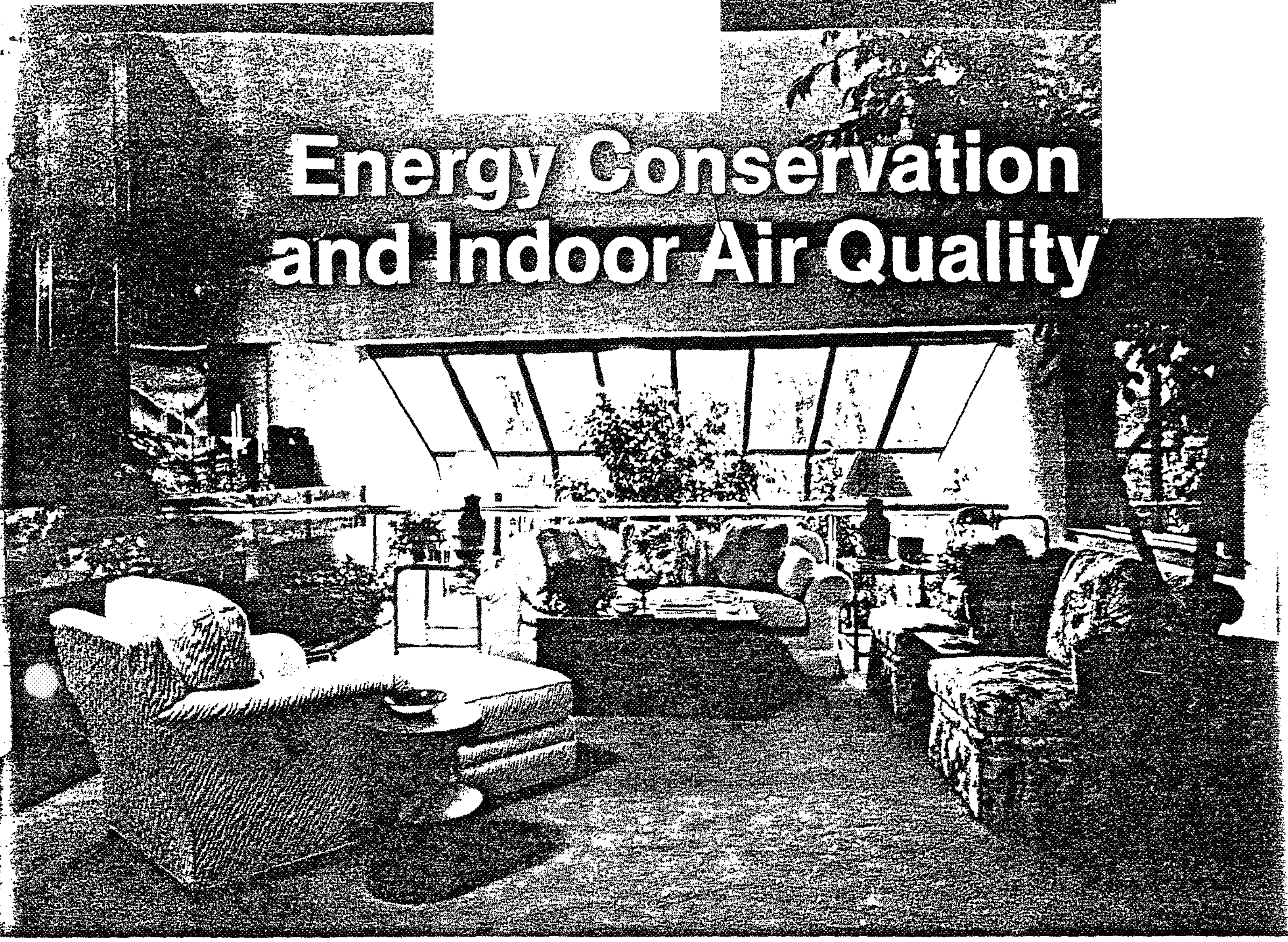
Energy Conservation and Indoor Air Quality



This paper reviews the topic of indoor air quality as it relates to energy efficient homes—both new homes and those which have been retrofitted to improve energy use. In the case of retrofitting existing homes for energy conservation, the author points out that because of their construction, common measures such as insulation, weather stripping, etc., should not create an indoor air quality problem.

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THE current and projected increases in the fuel market provide strong financial incentives to homeowners and builders to utilize energy more efficiently. One way is to reduce air leakage into and out of the building through cracks around windows, doors, and other openings. Another way is through increased levels of insulation in order to reduce temperature loss from the structure. Both of these methods offer excellent cost-benefit advantages to the consumer.

The indoor air quality question arises primarily as one result of techniques which reduce the infiltration of air. As the incentives to save energy increase, more and more complex efforts are being made to "tighten up" houses, by sealing effectively all areas of the home which historically have allowed houses to "breathe" or ventilate naturally. This natural ventilation traditionally has been the sole source of fresh air into the home during periods of extreme weather. As more sophisticated efforts are developed to stop this natural ventilation or air infiltration in homes, questions have been raised regarding the possible adverse effects on indoor air quality of extremely tight homes with very low natural ventilation.

The objective of this paper is to explain the indoor air quality issue as it relates to energy-efficient homes. Specifically, it will discuss ventilation in homes, the major types and sources of indoor air pollutants, and present some options for dealing with the pollutants while maintaining energy efficiency. It will discuss the fact that fibrous glass insulation does not affect indoor air quality.

VENTILATION IN HOUSES

There is considerable confusion concerning the "tightness" of a house. To clarify this issue it is necessary to understand what is meant by tightness, air infiltration, and natural ventilation.

Air Infiltration. Air infiltration is the process whereby fresh air enters a home. Possible sources of natural ventilation which occur in a house are cracks around windows, doors, and joints in construction. The infiltration of outside air is decreased by blocking and minimizing these air passageways using weather stripping, caulking or some similar technique. The degree of tightness will depend on how well air passageways have been sealed.

Insulation. Insulation or reinsulation accomplishes an entirely different objective. The goal of insulation is to reduce a building's temperature gain or loss by increasing the thermal resistance of walls, ceilings, and floors. Insulating or reinsulating an existing structure does not affect air infiltration; the insulation is not applied to locations where the infiltration occurs. For example, insulation is used to control the heat loss through a wall and is not used for restricting the flow of air around doors and windows.

"Tight" Homes. The total energy efficient design requires both the use of increased levels of insulation and a reduction of infiltration. The tightness

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of a house or building depends on how well ventilation or infiltration can be minimized and not on the amount of insulation used.

In the United States, most houses built before 1980 have infiltration levels which result in approximately one complete air change within the house per hour. This means that the various openings in the building envelope allow a volume of air into the house each hour approximately equal to the volume of air within the house. Energy efficient designs are aimed at reducing air leakage to levels approximately one-half to one-third of the previously mentioned levels, *i.e.*, 0.5 to 0.3 air changes per hour. These air exchange levels are determined with all doors and windows closed. The next section will examine the impact of these reduced levels of ventilation on the composition of indoor air.

INDOOR AIR QUALITY

Indoor air quality is a concept which defies an easy definition. Air quality in the United States has typically referred to outdoor air. The quality generally is related to levels of specific pollutants designated by the Environmental Protection Agency (EPA) as being acceptable with regard to human health. Outdoor air quality, then, is rather narrowly defined, and specific comparisons can be made between the outdoor concentrations of a specific pollutant and the level judged acceptable by the EPA.

Indoor air quality is a much more complex issue. First, there are no guidelines established for accurately assessing the quality of indoor air. Logic would dictate that the level of indoor pollutants should not exceed guidelines established for outdoor air.

Second, odors are subjectively perceived to have either an adverse (*e.g.*, pet odors) or beneficial (*e.g.*, perfume) impact on the quality of the indoor air. Such perceptible odors must be included as a component of indoor air quality.

Third, the control of moisture and humidity has an important role in indoor air quality. For example, high humidity leads to a sticky, uncomfortable feeling in the midwest and south. In colder climates, high humidity can lead to moisture condensation on windows and pipes, damp spots on wall and ceilings, mold growth, and even structural problems. Control of humidity, therefore, is another important aspect of indoor air quality.

These are the three major components of indoor air quality: the control of potentially hazardous air contaminants to acceptable levels, maintaining a low level of undesirable odors, and control of humidity.

AIR POLLUTANTS

Though a complete list of all substances which could find their way into indoor air could run longer than this document, only a small number of these have any real potential for causing health-related effects. Pollutants include the gases given off from combustion processes, such as cooling with natural gas appliances or from cigarette smoking (the gases are carbon monoxide and oxides of nitrogen), and small airborne particles (dust) arising from indoor activities, such as vacuuming or smoking. In addition, formaldehyde and radon have received significant attention in the press. Finally, as a result of natural ventilation, all contaminants present in outdoor air can enter the home.

Combustion. All open flame combustion processes generate some quantities of two potentially hazardous gases, carbon monoxide and nitrogen dioxide.

Carbon monoxide is an odorless, colorless asphyxiant gas whose reputation as a toxic agent is well known. Except in the case of a faulty ventilation system on an open flame combustion system, such as a fireplace or gas-fired space heater, carbon monoxide levels in homes, whether energy efficient or not, should not reach levels which would pose any threat to health.

Nitrogen dioxide is a reddish brown gas which is a pulmonary irritant. Animal studies have indicated that inhaling nitrogen dioxide gas at concentrations above the levels set by EPA for outdoor air can increase the susceptibility of the respiratory tract to infection. Though less well known, nitrogen dioxide has greater potential for creating a problem in the indoor environment. Several scientific studies published by the Harvard School of Public Health,[1] Lawrence Berkeley Laboratory,[2] and the United States government[3] have shown that the nitrogen dioxide levels in kitchens using gas ranges can exceed the recommended levels for outdoor air, even in houses or test facilities having air change rates of 1 to 2.5 air changes per hour.

The use of a properly functioning range hood may reduce the levels of nitrogen dioxide significantly; however, more research is needed. The potential long term health consequences of indoor exposure to nitrogen dioxide are unknown. Decreasing natural ventilation by sealing up a home would be expected to increase the levels of nitrogen dioxide in the kitchen area when the gas appliance was operating. Through the use of an efficient and operating exhaust system over the range, nitrogen dioxide levels may be kept to acceptable levels. The use of electric ranges does not result in the production of nitrogen dioxide in the residence.

Airborne Particles. Airborne particles represent a major contaminant of outdoor air. These particles range in size from sub-microscopic to the dust particles settling onto surfaces and easily visible to the naked eye. They are composed of a variety of materials including carbonaceous ash, various mineral salts, sea salt, pollens, bacteria, viruses, and a wide variety of metal oxides. Absorbed onto the surface of the nonviable particles may be a host of organic and inorganic compounds. A variety of health effects have been linked to airborne particles and limits have been set by EPA on acceptable concentrations for outdoor air.

It should be noted that outdoor air, in many parts of the country, exceeds these limits routinely. Indoor levels of airborne particles are a function of outdoor levels and indoor activities. Indoor activities may significantly increase the concentrations of airborne particles. Vacuum cleaning has been shown to increase airborne particles in homes by 100% or more[4]—a fact known by housewives and evidenced by the dusting which naturally follows rather than precedes vacuum cleaning. The most important source of particles in the indoor air is cigarette smoking. It has been estimated that to maintain airborne particles at a level below the limits set for outdoor air requires a 10-fold increase in the ventilation rate in a room if smoking is occurring. With the increasing awareness of the health consequences of passive cigarette smoke exposure (*i.e.*, occupying a room where there is smoking), smoking in a residence is taking on an added dimension.

Tightening up a residence for energy conservation may be expected to have a significant impact on indoor airborne particulate levels. By reducing leakage of outdoor air into the home, those particles occurring in the outdoor air would enter the house at lower rates and with time would lead to lower indoor levels. This has recently been demonstrated in tests conducted on a series of very tight homes with infiltration rates less than 0.5 air changes an hour.[5] During periods of indoor activity such as cleaning or cooking, indoor levels could exceed outdoor levels for brief periods of time. At this time, there is no scientific evidence relating indoor levels of airborne particles to any specific health effect.

Formaldehyde. Formaldehyde is a colorless, pungent, highly irritating gas, which, at low airborne concentrations, can cause a variety of symptoms including eye and throat irritation, and nausea.

Urea and formaldehyde are the basic ingredients of one type of foam insulation used in both new construction as well as retrofit application. As a result of complaints by homeowners in certain geographical areas following installation of urea formaldehyde foam insulation into wall cavities, several states now are proposing bans on urea formaldehyde foam insulation.

Particle board or plywood products sometimes contain residual free formaldehyde which is used as a component of bonding agents.

Conventional homes, other than those with problems arising from improper urea formaldehyde foam insulation, historically have not had problems attributed to formaldehyde. Unless strong sources of formaldehyde are present in a home, energy-conserving measures aimed at "tightening up" houses should not lead to problems of indoor air quality due to formaldehyde.

Fibrous glass insulation products use small amounts of formaldehyde as one element of a polymeric binder system which holds the glass fibers together in the insulation batt or blanket. This system is cured during manufacture, which prevents the insulation from giving off quantities of formaldehyde that would create the previously discussed symptoms.

Radon. Radon is a trace element found in soils and rock formations throughout the world. As it undergoes decay, a number of radioactive decay products or "daughters" are formed, the most important being radon^{222}. Radon^{222} is a gas which emits an alpha particle on further decay. These alpha particles are biologically active and under appropriate conditions can induce malignant transformation in biological tissues, *i.e.* cancer. Radon^{222} attaches itself to very fine, less than 1.0 micron, airborne particles which can be inhaled into the respiratory system. The lung, therefore, becomes the target organ for possible tumor induction. Miners working in uranium mines where a high level of radon is present have been shown to have increased incidence of lung cancer.

Since radon is a trace element found essentially everywhere, it enters the indoor environment through cracks in the building envelope and through diffusion from the soil through porous construction materials. Additionally, it may be present in deep well water supplies and enter the home in this fashion. Concern over indoor radon originated in two areas of the United States. In both instances, homes were built on soils containing very high levels of radon and subsequently had high radon emanation rates. Radon levels in some of the houses were found to exceed the levels considered safe. Due to the complex nature of the radon decay scheme, levels of radon are given in units known as Working Levels (WL). Though not yet promulgated, a 0.02 WL in a residence is likely to become the upper acceptable limit for indoor radon. The vast majority of houses in the United States in which radon has been measured have shown levels from five to ten times lower than 0.02 WL. Hence, indoor radon does not appear to be a widespread problem.

One experimental house constructed to be extremely tight (*i.e.*, 0.07 air changes per hour) was found to have high levels of radon— approximately seven times the 0.02 WL value. Studies performed by Lawrence Berkeley Laboratory[6] on this test home showed that increasing the air exchange rate to 0.6 changes per hour via an air-to-air heat exchanger reduced the radon levels to below the 0.02 WL limit. It should be pointed out that this particular house, which has been mentioned in nearly every article dealing with indoor air quality, also exhibited other signs of low infiltration such as extensive moisture problems and mold growth on the walls. The moisture problem was corrected immediately after construction by adding a dehumidifier.

Indoor radon should not be a cause for concern for homeowners or builders throughout the country, except in areas where high levels of radon are found in the soil. Most of these areas are recognized and known to local inhabitants or state health authorities. These are at least two ongoing programs, one in Florida and one in Canada, designed to reduce radon levels in homes built on high radon source soil. The results of these studies are anxiously awaited.

FUTURE CONSIDERATIONS

Indoor air quality in existing homes and those currently being constructed can be managed so as not to pose any potential negative health impact on residents. One commercial corporation has recommended design and construction criteria to build energy efficient homes.[7] These design options include vapor barriers to avoid condensation within the structure, humidity control to insure maximum comfort of the indoor environment and to eliminate excess humidity, electrostatic air cleaning devices which can reduce airborne particles to very low levels, and insulation to prevent energy loss through the building envelope. Extensive testing and research have been conducted at the technical center to evaluate the technology of energy efficiency. A significant negative impact on indoor air quality would not be expected when "tightening" a home. As it is not normally the practice to retrofit a vapor barrier to an existing home, it is unlikely that very low (*i.e.*, less than 0.5-0.6 air changes per hour) infiltration rates could be obtained and therefore adequate natural ventilation will remain. One possible problem which could arise would be with moisture condensation in the home, a situation readily rectified by humidity control devices.

In the future, as the drive for energy conservation continues, new construction techniques to improve energy efficiency will push air exchange rates from natural ventilation to very low levels (less than 0.1 to 0.2 air changes per hour), and it will become desirable to add systems allowing controlled mechanical ventilation of the home. Systems which provide for a supply of fresh air to be directed through air heat exchangers so as to preheat the incoming air currently are commercially available.

As technology progresses and more sophistication is used in constructing super energy efficient homes (less than 0.5 air changes per hour) totally controlled mechanical ventilation coupled with air-to-air heat exchanges, can lead to extremely energy efficient homes whose indoor air quality will be markedly improved over that in existing homes.

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