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Controlling Indoor Air Pollution in Energy-efficient Environments

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ABSTRACT

Indoor air pollution is an emerging health problem in the U.S. which is linked to energy conservation and the use of building materials. Recent investigation has revealed harmful pollutants in greater concentration in energy-conserving buildings than in the surrounding outdoor air. Some of the pollutants which have been found include particulate matter, carbon monoxide, formaldehyde, nitrogen dioxide and radioactive radon. In the use of some construction materials, measures intended to reduce the consumption of energy may contribute to the buildup of indoor air pollution. The characteristics of indoor pollutants and the major methods of control are reviewed.

RESUME

La pollution de l'air dans les espaces intérieurs devient un problème pour la santé aux Etats-Unis, celui-ci étant lié à la conservation de l'énergie et à l'utilisation des matériaux de construction. De récentes enquêtes ont révélé la présence de matières polluantes toxiques et plus concentrées dans l'air des bâtiments destinés à économiser l'énergie que dans celui de l'environnement extèrieur. On a trouvé notamment que ces matières polluantes contenaient du carbone monoxide, du formol, du nitrogène dioxide et du radon radioactif. L'utilisation de certains matériaux de construction, les mesures destinées à économiser l'énergie peuvent contribuer à la formation d'une pollution de l'air intérieur. Les caractéristiques de cette pollution et les principales méthodes de contrôle sont résumées dans cet article.

INTRODUCTION

Indoor air pollution is an emerging health problem in the U.S. which is linked to energy conservation and the use of building materials. Since the passage of the Clean Air Act in 1963, national attention has been focused on cleaning up the outdoor air, while little effort has been spent on the quality of indoor air. Recent investigation has revealed harmful pollutants in greater concentration in energy-conserving houses than in the surrounding outdoor air. In some cases, indoor pollution exceeds the national standards set for exposure outdoors. Since many people spend up to 90 percent of their time indoors, and up to half of that time in residences, the exposure to environmental pollutants can be substantial. Some of the pollutants which have been found include unhealthy levels of carbon monoxide, formaldehyde, nitrogen dioxide and radioactive radon. Exposure to these pollutants is usually involuntary, and the average resident has little or no way to monitor or control the level these substances. There is direct and circumstantial evidence that human exposures to these pollutants are large enough and common enough to account for substantial morbidity. However, the state-of-the-art does not permit the measurement or even estimation of the magnitude of this problem until further research is performed [1-3].

In the use of some construction materials, measures intended to reduce the consumption of energy may contribute to the buildup of indoor air pollution. For instance, one source of potentially harmful volatile organic pollution is a widely used insulation material, urea formaldehyde foam, which qualifies for a Federal Energy Tax Credit. Another problem of importance is the use of materials of earth origin which leads to increased exposure to radioactive radon gas. This paper presents a review of the characteristics of material-source pollutants and the major methods of indoor air pollution control in the non-work environment.

CHARACTERIZATION OF POLLUTANTS

One of the major difficulties in assessing the health impact of indoor air pollution is that the indoor environment is likely to include a complex mixture of pollutants [1, 6-8]. The complexity of the residential atmosphere complicates the interpretation of demonstrated correlations between residential pollutant levels and health effects. Some of the effects may be additive or cumulative; for instance, measurements of formaldehyde concentrations in the air may not reveal the full health consequences unless all volatile organics are evaluated at the same time. At present, there is little agreement on the amount of ventilation air required for the health, safety and comfort of building occupants. Some earlier studies of indoor air pollution have assumed that indoor contamination arises from outdoor sources and is directly related to outdoor concentrations, however, it is now recognized that numerous indoor air contaminants have their sources within the occupied spaces.

Indoor air contaminants generally fall into four categories. These are:

1. Dust and particulates.
2. Microorganisms and allergens.
3. Volatile organics and gases.
4. Radioactive substances.

A review of the major pollutants, their source, intensity and characteristics will be described in more detail below.

Dust and Particulates

Residential dust and particulates consist of dry granular particles and fibers. A sample of atmospheric dust usually contains soot and smoke, silica, clay, decayed biological matter, organic and mineral lints and fibers and metallic fragments. Almost all conceivable shapes and sizes are present, which makes the task of designing a comprehensive air cleaning system very difficult. The principal sources of fibers in residences are the insulating, covering and finish materials used during construction. Abrasion and mechanical vibration can result in increased concentrations of fibers in the indoor environment. Home exposure to asbestos due to aging, cracking, or physical disruption of insulated pipes or asbestos-containing ceiling tiles and spackling compounds may be greater than public exposures in schools, which have received the most attention. However, from what is understood about exposure-risk relationships for asbestos, it is judged to be a relatively small health risk.

Dust particles less than 2 µm in size cause the most medical concern because they are most likely to be retained in the lungs. Particles larger

than 8 µm are separated and retained by the upper respiratory tract. Unfortunately, removal of particles from the air becomes progressively more difficult as particle size decreases.

Microorganisms and Allergens

These pollutants include bacteria, viruses, plant pollens and other particulates [9]. Biological agents are often carried by respirable particles such as dust and cigarette smoke residue in the air and it is suspected that these particles may provide an important pathway for the transmission of communicable disease.

A major cause of illness and death among the elderly are upper respiratory infections transmitted from person to person in aerosols of small droplets, droplet nuclei and dust within closed buildings and vehicles, especially where people are in close association. From the point of view of public health and lost productivity, these respiratory viruses and bacteria are, by an order of magnitude, the most important pollutant of indoor air.

Volatile organics and gases

The major indoor sources of these pollutants are urea formaldehyde foam insulation, particle board, plywood, fabrics, and to a lesser extent cigarettes and indoor combustion sources. The high surface-to-volume ratio of particle board and plywood used as building materials contributes to high measured formaldehyde concentrations. Formaldehyde can cause skin, eye and throat irritation as well as respiratory disorders and allergies in occupants [10].

Radioactive emissions

The highest radiation dose from natural sources comes from the alpha-emitting daughters of Radon-222. This substance is an inert, radioactive, naturally occurring gas which is part of the uranium 238 decay chain. Any substance which contains radium 226, the precursor of radon, is a potential emanation source of radon and its decay daughters. Since radium is a trace element in most rock and soil, sources of indoor radon include building materials such as concrete or brick and the soil under building foundations. Tap water may be an additional source if its origin is in wells or underground springs. Radon readily migrates through foundations, walls, and floors and collects indoors. With a half-life of 3.8 days, it decays successively into several short-lived radioactive decay products that may be deposited and retained in the lungs, thereby exposing them to alpha radiation. Observations have shown that indoor concentrations of radon and radon daughters are often several times larger than outdoor concentrations. This is because the building envelope usually serves to confine radon emanating into the indoor air from various sources. Certain geographic areas in the United States have higher levels of radon in the indoor air, depending on the type and origin of building materials used. It has been shown that conservation measures, particularly reduced air-exchange rates, exacerbate this situation. As an example of the magnitude of its potential impact, background exposures to radon and its daughters could account for up to 10 to 20 percent of lung cancer in the United States among nonsmokers based on current risk estimates [11-15].

STRATEGIES FOR THE CONTROL OF INDOOR AIR POLLUTION

There are three major methods of controlling indoor air contaminants. These are: 1. Source control; 2. Dilution and ventilation control; 3. Removal control

Source Control

This technique of control includes the following three strategies:

1. Isolation of the source from the indoor environment, either by subsituting a different product or by prohibiting its use. An example is the prohibition of smoking in the home, or a decision not to use urea formaldehyde insulation in construction.
2. Containment or encapsulation of the source by treatment with paints or by enclosing the source with a film.
3. Local exhaust of a contaminant produced by a localized source with vent hoods and spot exhaust fans. The most common application of vent hoods in residences is the stove hood, used to remove cooking odors and smoke. Exhaust fans may also be used for more diffuse contamination removal such as for removing moisture from the bathroom or the whole kitchen.

Source control is probably the most cost-effective and energy efficient method of indoor air quality control.

Dilution and ventilation

This is the most common method of indoor air quality control. It may be achieved by three means:

1. By infiltration of air through openings in the building envelope which allow uncontrolled seepage of air.
2. By natural ventilation through windows, doors, vents, stacks or chimneys.
3. By forced or mechanical ventilation systems with provisions for moving air where it is wanted by use of ducts, dampers and fans. Filters may be used in conjunction with this method. Whole house ventilation systems control contaminant levels by flushing out polluted indoor air with outside air. This is a classic method, but may be very energy wasteful. Air-to-air heat exchangers permit whole house ventilation to be more energy efficient by recovering up to 70 percent of the heat (or coolness) which might otherwise be lost in the exhaust air.

Removal

Air cleaning devices which remove particles and gases from the air are commonly used as an alternative to or in combination with dilution control to reduce indoor concentrations of contaminants. These devices are generally of two types:

1. Particle removal devices which include mechanical filters and electronic air cleaners.
2. Gas and vapor removal devices which contain sorbents, such as activated alumina or activated charcoal.

No single type of air cleaning process is available which can control particles, gases and vapors. Air cleaners can be located either in forced air systems or directly in the occupied space. Mechanical filters remove particulate matter from the air and operate at efficiencies which are proportional to particle size. They range in effectiveness from the coarse fiber filters used on air intakes to remove lint and some dust from the air to the high efficiency particulate filters which remove 99.97% of the particles in the air above 0.3 um in diameter [16, 17]. Electronic air cleaners produce a positive charge on airborne dust, which is then precipitated on collection plates. There is a problem with electrostatic precipitation, in that locally high concentrations of ozone are produced [21].

VENTILATION STANDARDS

According to a survey conducted in 1979, buildings in the U.S. accounted for 38 percent of the total annual energy consumption. This is a higher percentage of the total than ten years previous, when buildings accounted for only 32 percent. The relative rise in energy consumption is not due to a failure in energy conservation in buildings, but rather to the recent extraordinary savings in the transportation sector. Of the total amount of energy used by buildings, ventilation and infiltration account for about 50 percent, or 18 percent of the total annual energy consumption of the nation [19,21]. Much engineering research is being done to define ways of reducing this large amount of energy used to heat, cool and move ventilation air. One method which has gained wide application is the sealing and weatherproofing of buildings in order to minimize air leakage, and to reduce ventilation in air-handling systems. Residences rely almost entirely on infiltration/exfiltration and door and window openings to provide ventilation. Infiltration/exfiltration is dependent on the tightness of the building envelope and is increased with indoor-outdoor temperature difference and wind speed. A recent study of 266 low-income residences in 14 cities throughout the U.S. shows an average rate of 0.9 air changes per hour, with the greatest rate being more than 4.0 air changes per hour [3].

Specially constructed experimental residences have demonstrated air exchange rates consistently below 0.2 a.c./h., and construction trends are towards "tight" houses [7]. Earth sheltered buildings are particularly well protected against unwanted infiltration, and easily achieve a minimum rate of 0.2 a.c./h. However, it seems that 0.4 to 0.5 a.c./h. is a more desirable "health-conscious" value for new residences. This represents a balance between the interest in energy conservation and health and comfort. Below 0.5 a.c./h., moisture buildup is noticeable due to cooking, bathing, washing and human metabolism. Such moisture buildup is easy to detect, since it results in condensation on windows, mildew, odors and other deleterious effects, and may serve as an early warning of low ventilation to residents.

In homes constructed to have infiltration rates below 0.2 a.c./h., it is possible to maintain adequate ventilation with a relatively small air-to-air heat exchanger. An average 120 square meter residence contains 1,055 cubic meters of air. To achieve a ventilation rate of 0.6 a.c./h.

would require that 633 cubic feet of air be exchanged. This requires a ventilation rate of about 11 cubic meters per minute which could be handled by a heat exchanger of 100 watts electrical power consumption. The heat energy saved by such a device would be as much as 10 times the power consumption, or one kW, on a cold day. The cumulative saving over the heating season can be considerable.

Acceptable indoor air quality in homes can be achieved by a combination of strategies outlined above, depending on individual needs and circumstances. Equipment to accomplish these tasks is available in the U.S. on a limited basis, mostly from European and Japanese manufacturers. Ventilation and air cleaning systems range in size from desk top electronic air purifiers for less than $100 to integrated central systems costing over $2,000 which meet the air quality control needs of the entire house. One such unit is an integrated system located in the kitchen, where it can be installed above the cooking range, replacing the hood. The unit is connected to ducts for supply and exhaust air throughout the house. Outdoor air is drawn into the unit, filtered, and distributed to the rooms. All exhaust air from the house is collected in one place where the heat is retained as the air is expelled. When food is being cooked, the exhaust rate from the kitchen can be increased. In this way, balanced ventilation, exhaust, heat recovery and air cleaning can all be accomplished with the same unit[20].

CONCLUSION

The lack of clear responsibility and authority at the Federal level in the U.S. has resulted in a reluctance to study indoor air pollution and has led to some duplication of effort. While Federal officials agree that a potentially serious health problem is posed, agencies find themselves assuming adversarial roles when assessing Federal actions on indoor air quality. In order to solve some of these difficulties, it has been recommended that the Environmental Protection Agency have primary authority and responsibility in this area. It is thought that the EPA could develop a comprehensive, coordinated program to study and control indoor air pollution using existing resources in both the public and private sectors [19, 20, 21].

There are cost-effective and energy efficient ways to minimize indoor air pollution, including proper ventilation and the use of air cleaning devices. Evaluations of air pollution control systems suggest that air-to-air heat exchangers used with air cleaning equipment will result in increased acceptability of interior environments at reduced energy consumption rates and operating cost.

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Measurements of Radon Daughters in 12 000 Swedish Homes

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ABSTRACT

Three factors cause a high radon and radon daughter concentration in Swedish dwellings:

1. By energy-saving measures the ventilation rate has become low
2. 10 per cent of existing houses are built of light weight concrete with a high proportion of radium
3. Large regions have high radium content in the ground

One way of finding houses with possible high radon daughter level is to measure the gamma radiation from the outside. In gamma radiating houses at least two detectors are installed to monitor the radon daughter concentration. This passive detector (5 cm x 5 cm) is sensitive only to alpha radiation, such as that emitted by radon and its alpha-radioactive daughters. The detectors are mounted in the middle of the room. After exposure for three months the detectors are returned for processing and reading. An alternative method of measuring radon daughter concentrations is to use filter sampling and a modified Kusnetz method and at the same time determine the ventilation rate in the dwelling using a tracer gas technique.

Among so far investigated houses almost 15 per cent, measured with passive detectors, have a radon daughter concentration higher than 400 Bq/m^3 (10.8 pCi/ℓ).

INTRODUCTION

In this paper results from radon daughter (Rnd) measurements in 12 000 dwellings are presented. Two different methods were used, a modified Kusnetz method and a track etch method. With the first method the Rnd concentration and the ventilation rate are measured simultaneously at nine different locations in a dwelling. The measurements of Rnd concentration are based on air samples