INDOOR AIR POLLUTION CONTROLS

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Abstract

Removal of indoor pollution generating sources prevents indoor air pollution. Modification of indoor sources, increase of the ventilation rates, pollution control devices, and other removal mechanisms mitigate indoor air pollution. This review addresses prevention and abatement mechanisms for pollutants or pollutant groups. Pollutants addressed individually are formaldehyde and radon, pollutant groups include particulate matter, products of combustion, and volatile organic compounds. Present level of knowledge is discussed for each topic, the effectiveness of each control mechanism is addressed, and non pollution effects such as potential conflicts with energy conservation measures, financial and other stresses are also considered. Finally, knowledge gaps are pointed out and research directions are suggested.

Introduction

Indoor pollution research is motivated by the need to reduce public exposure to elevated indoor pollutant concentrations. The premise is that such exposures cause adverse health effects and consequently the public must be protected. Scientific efforts have focused on establishing the statistical character of indoor pollutant concentrations and emission rates of indoor pollution sources, and on quantitating the health effects associated with indoor pollution. Proportionally little scientific effort has been devoted to reduction of indoor air pollution; yet decrease of indoor pollutant concentrations is one prerequisite for the protection of the exposed public.

Controlling the air pollution levels of indoor environments may be achieved by one of two generic approaches: (1) a pro-active course of action prevents the generation of indoor air pollution; and (2) a post-active approach reduces indoor pollutant concentrations to "acceptable" levels. A third option is the null action approach, this mechanism may not be acceptable to the indoor air quality technical community but it appears to be the prevailing practice. It is widely assumed that consumer interest associated with indoor air quality is increasing. There is however, little evidence to indicate that this interest translates to action (controls) in the residential environment. The emphasis of control systems applications has been on non-industrial public buildings including restaurants, hotels, schools and office complexes. One noteworthy exception, elevated concentrations of formaldehyde in residential environments have been reduced by a world wide effort. Efforts to control indoor radon concentration are less successful than the formaldehyde experience, yet they are more focused and more promising than the efforts to control other contaminants.

Prevention of Indoor Air Pollution

The most effective mechanism for preventing indoor air pollution is to remove the source which emitts air pollutants indoors. If a source is confined so it either emitts outside the indoor environment or in certain isolated areas, air pollution is prevented efficiently. A third mechanism addresses the emission rate of a source, an "improved" and/or properly maintained source results in lower indoor pollutant concentrations.

Source Removal

Environmental tobacco smoke is attracting attention and controversy (6). Recent findings regarding passive smoking have led to well orchestrated and widely successful effort to forbid smoking in public buildings. A most successful indoor air pollution control mechanism, it has met with resistance from smokers, the tobacco industry and restaurant associations. This mechanism is enforceable in public buildings, but it can not be enforced in the residential environment where a large portion of passive exposure to environmental tobacco smoke takes place. Yet, public relationship efforts are effective in the USA in reducing cigarette consumption by adults.

In accordance with a linear zero-threshold model, asbestos is a carcinogen, that is any level of airborne asbestos presents a risk. The major concern relates to public exposure to airborne asbestos at concentrations much higher than outdoor asbestos levels. Possible degredation or disturbance of in-place asbestos containing materials in buildings causes high airborne concentrations. The regulatory framework is set in the U.S.A., the asbestos is to be removed from schools, Federal Register (2) . Once again little evidence exists to indicate asbestos-source removal from residential environments.

Partial source removal frequently leads to desirable controls. Experimental results by Godish and Rouch (5) from a residence show that removal of 15 percent of plywood resulted in 49 percent reduction of formaldehyde indoor levels and removal of half of the particle board reduced HCHO concentrations by 29 percent.

Source Redirection and Confinement

Source redirection/confinement is another generic mechanism that prevents indoor air pollution. In a recent paper, Fisk (3) reviews efforts to divert radon gas from entering indoor environments. In this paper he reviews several techniques, including sealing, crawl space ventilation, subslab ventilation, basement pressurization, and venting cavities within concrete block walls. Various degrees of success have been recorded, further work is needed to quantitate the efficiency of each mechanism and to reduce the costs that would make applications widespread. Table 1, by Henschel

(7) presents radon control technologies and shows approximate installation and operating costs. Costs associated with indoor air pollution controls will be addressed later.

The use of barriers has also found application with formaldehyde emitting sources. Matthews (9,10) and his associates have studied such control methods, their studies point to varying degrees of success. Coating of formaldehyde emitting surfaces with chemicals that react with HCHO has also resulted in variable degree of success in preventing elevated indoor formaldehyde concentrations Fisk et al. (4).

Redirection of pollutants by venting products emitted by a source prevents them from becoming airborne indoors. Unvented indoor pollution sources include kerosene heaters, gas ranges, gas space heaters and others. Elimination of such sources is an option which may lead to undesired financial burdens, however venting outdoors the contaminants emitted by such sources is a practical approach, imposed by regulation in several European countries. Source venting is obviously effective in preventing indoor air pollution, it is estimated that as much as 77% of the contaminants from an unvented gas top burner will be vented outside if a hood is operating, Revzan (18). Increase of ventilation rates may, however, lead to impacts that are not desirable for the energy point of view.

Source confinement is a method of preventing widespread indoor air pollution. Following the airplane model allowance for smoking areas within restaurants or office buildings appears to be a compromise that reduces indoor air pollution. Similarly, isolating areas with known indoor air pollution sources from the rest of the indoor environment may lead to occupant activity patterns which will reduce exposure to indoor pollutants. The topic of source confinement on exposure levels has not been investigated in depth, yet it is a clear compromise with both financial and social advantages.

Source Improvement

Source removal or redirection of emitted contaminants may require psychological and/or financial burdens that the consumer is not ready to accept. There is another option that prevents indoor air pollution: Source improvement. The literature provides many examples of technical success. Paint with lead is an early source of indoor pollution, presently all paints have been improved and do not contain lead. Fireplaces and woodstoves constitute an intermittent source of indoor air pollution especially during wood stocking. Improved designs of these sources have reduced considerably the possibility of indoor air pollution. An improved two stage kerosene burner emits less CO and NO_2 (about 50% less) than an one chamber kerosene heater, Fisk (3). The addition of electronic ignition in unvented gas appliances eliminates as many as three pilot lights and prevents elevated baseline levels of indoor CO and NO_2 concentrations.

TABLE 1. APPROXIMATE COSTS OF RADON MITIGATION (EXISTING HOUSES)

Technique	Approximate % reduction	Installed Cost ($) By Homeowner	By Contractor	Annual Operating Cost
House Ventilation				
1. Natural	Up to 90	0		4 times heating costs.
2. Forced	Up to 90	Low	To 150	Up to $100 + 4 times heating costs.
3. HRV	Up to 90+	—	400–1,500	Up to $100 + 1.6 times heating costs.
Sealing				
4. Comprehensive Sealing	Low to 90 moderate	Low to >10,000	Low to	"None"
Active Soil Ventilation				
5. Wall Ventilation				
- Single point	Up to 99+	100–400	2,500+	$150
- Baseboard duct	Up to 99+	200–600	5,000+	$150
6. Sub-slab ventilation	Up to 90–99	200–500	2,000+	$150
7. Drain tile suction	Up to 98+	100–300	1,200	$150
Passive soil ventilation				
8. Sub-slab ventilation	*		*	None
Home pressurization				
9. House pressurization	*		*	*
Avoid Depressurization				
10. Avoid depressurization	*		*	*
Air cleaners				
11. Particle removal devices	*		*	*
12. Gas sorption devices	*		*	*
Well water treatment				
13. Water treatment devices	*		*	*

*Performance/costs highly variable, site-specific (or otherwise unable to estimate at this time).

Maintenance of indoor sources has not been studied extensively. yet the age of appliances Moschandreas and Relwani (14) , the location of the air shutter, blue flame vs yellow flame, the presence of pilot lights, Macriss et al. (8) and the wick location, Trayner et al. (19) point out that maintenance of these types of sources will prevent substantial increases of indoor air pollution. Technical progress with commercial adhesives and wood products has improved a potential source of indoor formaldehyde (HCHO) to such degree that indoor air HCHO concentrations can be reduced to ambient formaldehyde levels, Meyer (11). While this optimistic point of view is not shared by all researchers it does point to a success of source improvement. One of the concerns with source improvements relates to substitution of one contaminant by another contaminant, this obviously must be avoided.

Indoor Air Pollution Abatement

Abatement of indoor air pollution is another control approach that leads to reduction of public exposure to pollutants. Control systems and dilution by fresh air are employed to decrease the pollutant concentrations to acceptable levels.

Control Systems

In general the technology for controlling indoor concentrations of particulate matter is more mature than the technologies for controlling indoor gaseous pollutants. A recent document by ASHRAE (1) deals with systems that control the levels of particulate matter of indoor environments by "clearing" ventilation air and recirculation air. Efficiency, air flow resistance and dust-holding capacity are three operating parameters that determine the quality of the control system. Efficiency refers to the capacity of a filtering system to remove particulate matter from an air stream; air flow resistance is the static pressure drop across a filter at a given air flow rate; and dust holding capacity is the amount of standard dust that a filter can hold at a given flow rate before its dust removing efficiency is reduced. There are three types of cleaners inserted in the HVAC system: (1) Fibrous media Unit Filters, which vary in efficiency with time and are replaceable; (2) Renewable Media Filters, which maintain constant resistance and efficiency by introducing fresh media when they are needed; and (3) electronic air cleaners which properly maintained have constant efficiency. An additional type of cleaners, the room air cleaners, have been introduced recently as stand along units outside the HVAC system. There is no one standard technique that determines the efficiency of a particulate matter cleaner in air stream, four test types are used: (1) arrestance; (2) dust spot efficiency; (3) functional efficiency; and (4) particle size efficiency. While one standard does not exist, many measurements have been made, Figure 1 shows a compilation of data obtained from manufacturers.

An "Electronic Air Cleaner" is defined by ASHRAE as an electrostatic precipitator used for HVAC filtration. The Electronic air cleaner consists of two components (1) the ionizing section and (2) the collecting plate section. When properly designed, operated and maintained electronic air cleaners may remove up to 98 percent of airborne particulate matter (tested by ASHRAE Standard 52). This removal maximum rate reduces with increasing air flow velocities, with variable air flow velocities and with increasing particulate matter load.

This discussion on reducing indoor particulate matter levels has focused on systems that are components of an existing HVAC unit; stand along air cleaners are also manufactured, they are known as room air cleaners. When such units are evaluated the concept of "Effective Cleaning Rate" (16) or the "Clean Air Delivery Rate" (13) is employed. These rates refer to the volumetric rate of contaminate-free air required to produce the contaminant reduction affected by the operation of a room air cleaner. A chamber decay method is used to determine the room air cleaner effectiveness in removing environmental tobacco smoke and other small aerosol sizes. The Association of Home Appliance Manufacturers is employing this approach to test the cleaners effectiveness for removing environmental tobacco smoke, dust and pollen. The literature indicates a wide range of performance of such devices depending on their size, principle of removal and indeed the procedure used to test them.

Abatement of elevated concentrations of gaseous pollutants can be achieved by chemical sorption, vapor ventilation, combustion and scrubbing. These mechanisms require specialized rather large and, possibly expensive equipment, they are applied in large indoor environments such as office buildings, animal laboratories and hospitals. The objective of installing such units is to reduce odoriferous vapors and their impact on the occupants. Miniaturization of the larger units inside houses has been attempted, the results are not clearly documented but are perceived to be less successful than in large buildings. Installation, operation and maintenance costs are assumed to be high. Research is presently directed in two directions: (1) Identification of materials and mechanisms which are less massive and less expensive than present adsorbent equipment and require little or no maintenance; and (2) Integrated systems that employ special mixture and design of desiccant beds that adsorb water vapor and NO_x, SO_x and VOCs and regenerate with minimal impacts from the occupants of residences, Moschandreas and Relwani (17). It is too early to discuss the efficiency of such systems in residential applications.

Dilution

It is generally assumed that outdoor air is less polluted than indoor air. It follows that dilution of indoor air with outdoor air will reduce the magnitude of indoor pollutant concentrations. ASHRAE (1) has revised its standard 62-1981 on "Ventilation for Acceptable Indoor Air Quality". In an effort to balance energy and air quality requirements, ASHRAE has determined outdoor air requirements for ventilation rates in cfm/person (usually 15 cfm/person or more) for many commercial facilities including offices, hotels, convention facilities, retail stores and others. Similarly ASHRAE established a minimum ventilation rate for residences to be 0.35 air changes per hour but not less than 15 cfm per person. Lower ventilation rates than the recommended can be achieved by present building

technology. if such is the case, mechanical ventilation systems must be employed to assure acceptable indoor air quality. Factors such as mixing, local ventilations or variable ventilation rates must be addressed to assure that acceptable indoor air quality is achieved when it is needed, where it is needed with the least possible financial burden to the occupants. Present technology is capable of achieving the recommended rates; caution however must be advocated toward maintenance of the systems and verification that the ventilated air (outdoor and treated recirculated air) is less polluted than the indoor air it is diluting.

In a recent paper, Fisk (3) documents that adherence to the recommended ventilation rate does not necessarily lead to acceptable indoor air quality because emission rates of sources vary widely. He simulates indoor environments using a steady-state mass balanced equation and concludes that "...an inexpensive increase in ventilation rate, for example an increase of 0.2 ach, could lead to a large improvement in indoor air quality if the initial ventilation rate is low but has little impact on indoor air quality if the initial ventilation rate is high". This point is made by Moschandreas and Relwani (15) not only for steady state conditions but for intermittent/dynamic simulation of emissions by a range top burner, see figure 2.

Assumptions, Assertions and Recommendation

Control Technology is driven by either regulatory activities or consumer desire to improve the standard of living. Regulatory activities (government standards and/or guidelines by professional societies) are increasing with increasing technical interest on indoor air quality. The consumer interest is really unknown, it is assumed that it responds to media reports and to personal requirements rather than societal concerns.

Consumer Motivated Control Technology

It is assumed that the consumer wishes to avoid illness induced by exposure to indoor air pollution. As indicated by public calls for non-smoking areas in office buildings, restaurants and other public indoor environments, by an increasing number of requests to mitigate the sick building syndrome, and by repeated consumer requests to check whether individual residences are polluted by increased levels of radon, ETS or VOCs, concern about indoor air quality is increasing. IAQ Control Technology is directly affected by such increased concern in many ways. Firstly, control devices are appearing in the market in increasing numbers. Success claims are, however, frequently beyond actual performance. It is recommended that the government and the technical community establish standard operating procedures to test such claims. Presently in the USA, the Federal Trade Commission (FTC) checks advertising claims, this is an inadequate approach because the technical basis of this particular agency is not strong, the R & D portion of the needed justification must be performed by others, such as EPA or CPSC. Secondly, while consumers demand clean air in public indoor environments, they are not willing to undertake the financial burden to assure clean air in their own residences. Results from a risk analysis survey employing a risk ladder indicate that over 80 percent of the subjects surveyed (presently 88) are not willing to pay more than $150 annually to reduce exposure to indoor air pollution. If these preliminary results from a pilot study, which is conducted by the author of this paper, are generalizable they lead to two conclusions: (1) All indoor air control devices must be inexpensive and almost maintenance free; and (2) prevention is the best mitigation of residential air pollution. Thirdly, the consumer interest is driven by publicity. The above mentioned survey was conducted in three segments: (i) one immediately after a local television had a week long series on radon in houses; (ii) the second followed a similar investigative report on ETS and adverse effects of passive smoking; and (iii) the last segment was surveyed following no particular media reports on IAQ. Subjects stating their perception of the contaminant of greatest concern followed the predictable path the first segment identified radon as the pollutant of maximum concern, the second ETS and the third did not identify a predominant contaminant.

Results of this work, which in progress, indicate that indoor air pollution may be an acceptable risk in our houses and that the technical community needs to focus more effort in educating the public. Education may be the best control technology because prevention provides exactly what the consumer demands: inexpensive and effective controls that eliminate indoor air pollution.

Standards and Guidelines

A set of desiderata must be satisfied before an air pollution standard is promulgated by a regulatory entity: (1) Risk Analysis based on health studies must be formulated; (2) Cost/Benefit studies must be performed; and (3) The efficiency of best available control technology must be evaluated. A synthesis of results from such studies result to a standard that protects public health efficiently.

Consensus guidelines are based on state-of-the-art knowledge, and protect all involved by setting procedures to assure acceptable indoor pollution levels. The author assumes that there is a marked difference between the two processes: government standards are the fruits of a detailed scientific process and reflect national policy, the guidelines are less rigorous, but they provide the best thinking of the concerned society. The guidelines are necessary but generally not sufficient, not the end goal but a necessary step toward the goal. Finally guidelines provide practitioners of IAQ control technology with target levels that must be reached when controls are implemented.

Presently, the interests of control technology research, development and application are focusing on two pollutants: Radom and asbestos. The control science for asbestos is mature (although research for improvements is going on) and appropriate removal procedures have been established. For radon, R & D is increasing because the risk & cost/benefit work is on sound grounds, a firm IAQ standard/guideline (4 pCi/l) has been established and the best available technology is being investigated.

Risk assessment on NO_2, VOC and ETS is either incomplete and inconclusive (NO_2 and ETS) or has just started (VOCs) and there is no basis for implementing detailed cost/benefit studies. For these pollutants, the avenue followed by concerned scientists and consumer advocates is the setting of guidelines by appropriate professional societies.

The author of this paper believes that in the case of NO_2 (and other combustion products) and VOCs the adverse health impact may be too small to quantitate by conventional studies. Health experts and epidemiologists will require a very large sample size to determine an impact that may not be that serious. Three options are available to control technology practitioners: (1) wait for health studies to identify a safe level (this may be equivalent of no action); (2) employ best available technology which is continuously improving; and (3) direct funds to control technology research in order to meet present standards or guidelines. It is the authors assessment that the Indoor Air Quality community is focusing on the first option, pays some attention to the second option, but should emphasize the third one.

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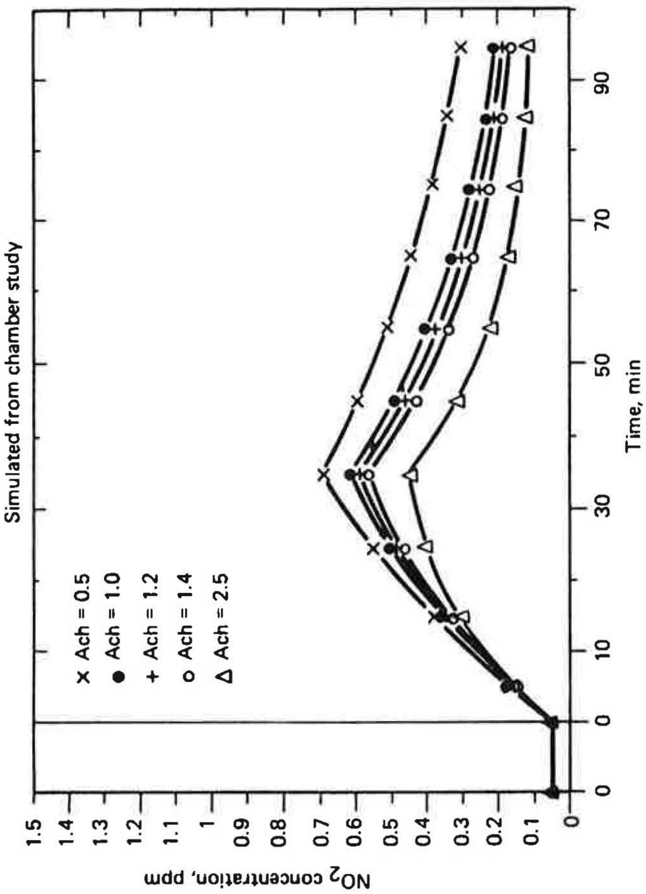

SELECTED PARAMETERS

(1) Range top burner (9000 Btu/hr) operating at Blue flame condition

(2) Kitchen volume = 1000 ft^3

(3) Chemical transformation rate = 0.6 h^{-1}

(4) Air infiltration rate = 0.5, 1.0, 1.2, 1.4, and 2.5 h^{-1}

Figure 2. Estimated NO_2 concentration vs. time.

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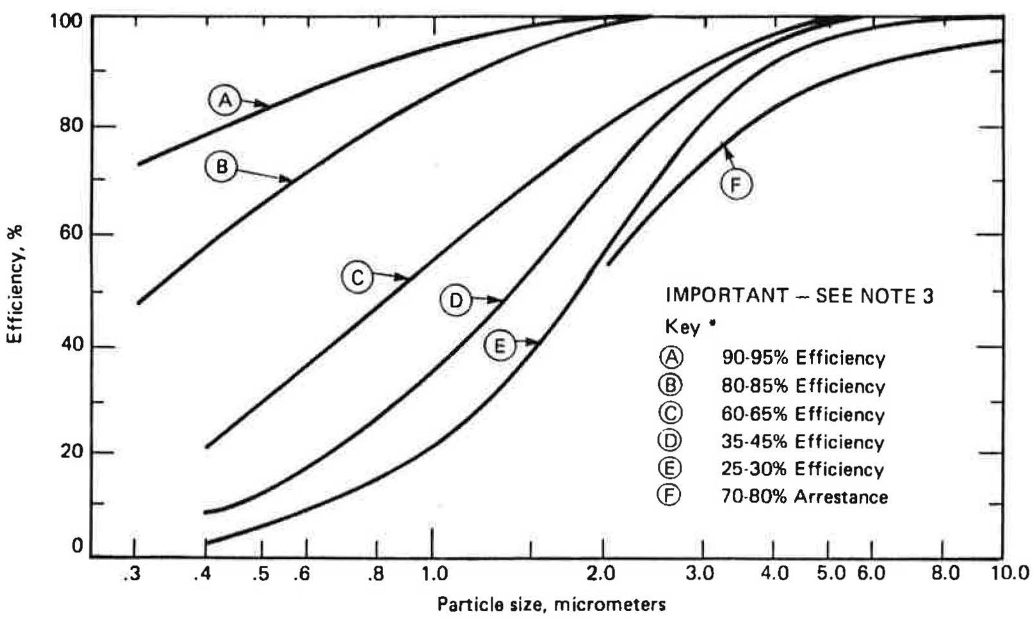

NOTES:

1. Compiled and averaged from data furnished by manufacturers.
* 2. Efficiency and arrestance per ASHRAE Standard 52-76 test methods.
3. CAUTION: Curves are approximations only for general guidance. Values from them MUST NOT be used to specify air filters, since a generally-recognized test standard does not exist.