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Rationale and Plan for Center for Building Technology Research to Improve Indoor Air Quality

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report outlines a suggested five year research plan for the Center for Building Technology (CBT) in support of resolving the emerging indoor air quality problem. The problem is defined, and the past research is summarized. The important Federal responsibilities are identified. NBS contributions and capabilities are noted. Future research needs are covered, and these form the basis for the CBT research plan, in cooperation with other Federal agencies, state and local governments and the private sector.

Key Words: Chemical measurements, engineering, indoor air quality, models, physical measurements, research plan.

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PURPOSE

The purpose of this report is to suggest a five year Center for Building Technology, (CBT) research plan as part of the important national research effort to improve indoor air quality (IAQ). Brief summaries are included covering the importance of the issue, and the responsibilities of several other Federal agencies in the area. The research status is reviewed, focusing on areas in which further research is indicated. The National Bureau of Standards, (NBS) technologies are covered emphasizing those appropriate to the NBS mission in the broad area of indoor air quality. A suggested CBT research plan, in cooperation with other NBS units, is then presented.

IMPORTANCE OF INDOOR AIR QUALITY

Much attention has been accorded to outdoor air pollution in the past, primarily an Environmental Protection Agency (EPA) responsibility. In addition, the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have had significant effects on the air quality of the work environment, primarily in industrial situations. Less attention was paid to residential and commercial indoor air quality. However, surveys shows that 80-90% of the average person's time is spent indoors and a large fraction of that is spent in residential or commercial environments (1). The quality of these environments warrants more attention. In recent years a number of problems have arisen and research has been accelerated. Legionnaires disease, "sick building" syndrome, radon in buildings, formaldehyde from Urea Formaldehyde Foam Insulation (UFFI), chipboard, etc., are only a few of the problems. Many recent studies (2-5) have pointed out concerns about indoor air quality in residences and commercial buildings. Concentrations of many pollutants have been measured at levels which exceed standards set for outdoor and industrial exposures. Energy conservation efforts, leading to better sealed structures, increase the concentration of any internally generated pollutant. This is especially true in new construction. Some new materials and processes introduced into structures outgas pollutants, and the increased use of unvented heating appliances tend to exacerbate existing problems. Enough evidence has accumulated to raise serious questions about the ability of our indoor environments to protect the health and safety of occupants in many different situations.

Much is known about general control methods. Ventilation can be increased at an increased energy and equipment cost, air treatment devices can be used, pollutants can be controlled at the source or substitute materials can be used. However, some possible solutions are often not economically feasible. For example, it has been proposed to equip all residences with air-to-air heat exchangers to increase ventilation rates, thereby conserving energy and improving indoor air quality. These have been estimated to cost $500-$1,000 installed (6). To apply them to the 80 million U.S. dwelling units would require a $40-$80 billion investment! This is not a practical solution! While heat exchangers may be practical cost-effective control means in some applications, it is presently impossible to predict in which residences heat exchangers would be cost effective. Each building is different in its indoor contaminants. To predict the value of controls, we must know the current and projected distribution of pollutants and their concentrations in a large sample of different buildings. We must further know the short and long term health effects of the pollutants on people. To do this peoples´ temporal and spatial exposure patterns must be known as well as the epidemological effects of pollutants. The efficacy and practicability of known and future control strategies, (dilution, removal, exclusion, suppression, and occupant actions) must be ascertained for the multitude of applications. Only then can appropriate rational, technology-based policies and recommendations be made. Until then, recommendations with incomplete data must be employed to solve immediate real or suspected problems.

FEDERAL RESPONSIBILITIES IN INDOOR AIR QUALITY

At the current time, several Federal agencies share responsibility for various aspects of indoor air quality. The Environmental Protection Agency has five important mandates, 1. The Clean Air Act; 2. The Safe Drinking Water Act; 3. The Federal Insecticide, Fungicide and Rodenticide Act; 4. The Toxic Substance Control Act; and 5. The Uranium Mill Tailing Act. Congress has established the Environmental Protection Agency as the lead agency in coordinating further public-funded research on indoor air quality.

The Department of Health and Human Services, through the National Institute for Occupational Safety and Health, the National Institute for Environmental Health and Safety, the Public Health Service, and the Centers for Disease Control have broad responsibilities for the public health, and have long been involved in air quality studies, particularly in industrial situations.

The Department of Energy has a mandate to encourage safe energy conservation measures in buildings and for appliances.

The Bonneville Power Administration and Tennessee Valley Authority, (part of the Department of Energy), establish safeguards to protect public health for customers in their service areas as part of their energy conservation programs.

The Consumer Product Safety Commission is charged with protecting consumers from products which pose a threat to health and safety, such as unvented combustion devices, building products and systems, and small appliances.

The Department of Housing and Urban Development must ensure that health care facilities and homes covered by Federal mortgage guarantee programs meet minimum standards for the protection of health and safety.

The General Services Administration, as builder and manager of Federal buildings, establishes criteria for their design and performance.

The Department of Defense, the world's largest owner of buildings, is responsible for providing healthful environments on DOD jobsites and base housing.

The Federal Trade Commission mandate is to protect the public from misleading or false advertising.

The Department of Transportation establishes standards for public terminals, including airports and bus stations.

The Department of Labor's Occupational Safety and Health Administration sets standards for air pollutants at industrial and some commercial job sites.

The Nuclear Regulatory Commission issues standards for technology-based ionizing radiation exposures.

In addition, the Department of Education is concerned with school health and the Federal Aviation Authority is involved in air quality in aircraft cabins. There are other agencies such as the U.S. Department of Agriculture and the Veterans Administration which also have roles.

The Federal Interagency Committee on Indoor Air Quality (CIAQ) was formed in 1979 to coordinate Federal research among the interested agencies, including CBT. In 1983 the committee was reorganized by congressional mandate. Four co-chairs were appointed. The EPA representative, Don Ehreth, is chairman, with representatives from DoE, HHS and CPSC as co-chairs. Sixteen Federal agencies including NBS (and CBT) are represented.

Since 1983, the Interagency Committee on Indoor Air Quality has been very active. It organized several working groups concerned with:

Radon
Formaldehyde
Organic Chemicals
Combustion Sources
Pathogens and Allergens
Structure Characteristics
Field Studies

These groups first identified the state of research in their areas, and the organizations and laboratories which were performing significant research. Then each group drafted a suggested research strategy. The co-chairs organized a coordinated document, a "Comprehensive Indoor Air Quality Research Strategy" (7). After review by the entire committee, it was submitted to OMB, which approved it in March 1985. It was then submitted to Congress. This strategy is summarized later and is the primary basis for the CBT research recommendations.

NON-FEDERAL ACTIVITIES

Research is done by many in the non-Federal community. Much work is of a proprietary nature and not easily available. Other work is done by universities, the national laboratories, etc., with much funding from government sources. Mentioned here are a few organizations which are active, but this section cannot cover all the important contributions. Only entities thought to be useful for future contacts and research planning are mentioned.

Professional Societies and Associations - the American Society of Heating, Refrigerating and Air-Conditioning Engineers, (ASHRAE) has a research program in IAQ and writes voluntary standards. The American Society for Testing Materials, (ASTM) writes voluntary standards. The Air Pollution Control Association, (APCA) is concerned. The American Hospital Association, (AHA) is active in the area.

Industrial Research Groups - The Electric Power Research Institute, (EPRI) and the Gas Research Institute, (GRI) are actively sponsoring IAQ work. Battelle and A.D. Little also have work underway, as well as others.

State and local governments, and energy utilities also have contributed.

GENERAL TECHNICAL ISSUES AND BACKGROUND

The many contaminants in the indoor air can be divided into particulates (solids or liquid droplets) and gases or vapors. Within these types, there are constituents which are known to be annoying and which are, or are suspected of being, damaging to health. Others may be identified in the future. Constituents which are annoying may impair human performance without being deleterious to health. ASHRAE Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality" (8), defines acceptable air quality as "air in which there are no known contaminants at harmful concentrations and with which a substantial majority of the people exposed do not express dissatisfaction." This recognizes both the health and comfort requirements of acceptable air quality.

Some known important contaminants are discussed below:

Particulates - Standards often specify a limit of the mass concentration of particulates expressed as micrograms per cubic meter (μg/m3) (9). These include all particle sizes, or total suspended particulate concentration (TSP). Larger sizes may constitute annoyance more than health problems. For health, respirable suspended particulates (RSP) are important, because such particles can lodge in the lung. Large particles lodge in the nasal passages and are handled ordinarily by the person unless they are, or contain, allergens or pathogens. Respirable particles are in the size range up to 10 micrometers (μm).

Particulates of specific interest include:

1. Respirable particulates as a group
2. Tobacco smoke (solid and liquid droplets) (tobacco smoke also contains many vapors and gases)
3. Asbestos fibers
4. Allergens (pollen, mold spores, insect feces and parts)

5. Pathogens (bacteria and viruses), almost always contained in or on other particulates
6. Radon progeny (radioactive decay products of radon gas, the first radioactive decay product of radium, which is ubiquitous in the earth's crust).

Vapors and gases of particular interest include:

1. Carbon monoxide
2. Radon (decay products become attached to solids)
3. Formaldehyde and other aldehydes (require special attention as organics)
4. Other volatile organic compounds (VOC) (several hundred have been identified in tobacco smoke vapors alone)
5. Oxides of nitrogen
6. Chlorinated compounds (pesticides and solvents)
7. Carbon dioxide
8. Sulfur dioxide

Some contaminants enter with the outside air brought in by purposeful ventilation or by uncontrolled infiltration. In the U.S., the EPA has established outdoor pollutant criteria (9) and the public interest in outdoor pollution has resulted in considerable action to improve it. Currently, except for some local areas, the outdoor air quality is not considered a significant health or comfort threat. Many of the contaminants found in the air outdoors do not occur in high enough concentrations to cause concerns, but have recently been recognized as indoor health concerns. Examples are nitrogen oxides, carbon monoxide and formaldehyde. However, most important indoor pollutants emanate from inside sources or are concentrated there. People are sources of CO_2, and biomatter, as well as other particulates and vapors which are characterized as "body odors." People's activities, smoking, cleaning, hobby activities, such as gluing plastic models and refinishing furniture, cooking, etc., also cause pollution. Building materials and finishes can "outgas" pollutants. Furnishings, business machines and appliances, particularly unvented or poorly vented heaters and ranges, can be sources. The building surroundings can be a source of radon and insecticides which enter the indoors through cracks, drains, etc., or by diffusion. Heating, ventilation, and air-conditioning (HVAC) systems, drains, plumbing systems, and poor construction, housekeeping, and maintenance can result in "environmental niches" where pathogens or allergenic organisms can collect and multiply to be reintroduced into the air (10).

Similarly, there are many mechanisms which remove contaminants from the indoor air. General and local exhaust systems are important, as is the uncontrolled exfiltration of inside air. Particulates also settle on horizontal surfaces due to gravitational forces and are precipitated on all surfaces by electrostatic forces, diffusion and air motion.

Vapors and gases can be absorbed or adsorbed on materials of many kinds, and can react with other airborne pollutants and be changed in character. All of the above mechanisms occur continuously at generally uncontrolled rates.

Air cleaners can be used to remove contaminants. Particulate removal techniques are well developed (11-12). Gaseous removal is less so, with activated charcoal and potassium permanganate being most highly developed (12).

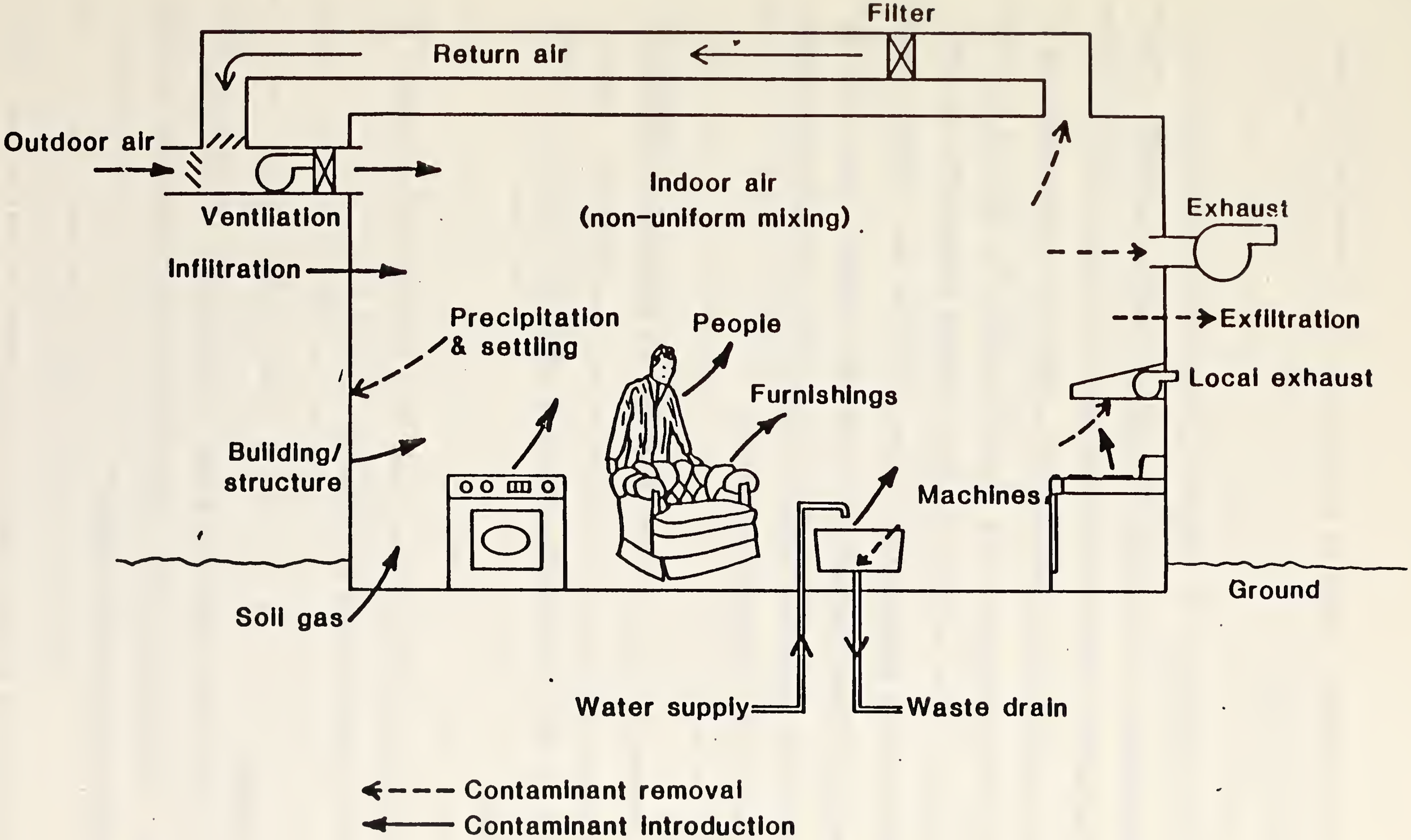
An additional complicating factor in contaminant concentration is the non-uniform mixing which is often present in buildings. Concentrations vary spatially as well as temporarily. Pollutants may emanate from point sources, such as an unvented space heater, or area sources, such as wall panels, which adds further non-uniformity to the concentration.

Figure 1 shows graphically the general indoor air pollution situation, including many of the mechanisms of the entrance, removal, and circulation of pollutants.

The complexity of the problem requires careful research planning, employing experts representing many technologies. Otherwise, data collected will have limited utility for providing a useful data base for the development of generally applicable and economic methods for improving indoor air quality and for developing national policies.

STANDARDS AND GUIDELINES

The EPA has been active for years in setting standards for outdoor air (9). HHS (NIOSH) (13-14) recommends standards for industrial workplace environments. OSHA (15) issues workplace standards promulgating NIOSH recommendations. The American Conference of Governmental Industrial Hygienists (ACGIH) (16) has, as a professional society, issued workplace standards, as has the American Industrial Hygiene Association (AIHA) (17). These agencies have concentrated on the outdoor air and the industrial workplace environments. While these standards for some particular pollutants may be useful for other indoor environments, those non-industrial environments are not specifically covered. A majority of people spend most of their time living, working and visiting residential and



Generalized Indoor Air Contaminant System

Figure 1

commercial environments, therefore the need for better standards for these environments is evident.

Since 1946, ASHRAE has been the only professional society producing voluntary standards (with the American Standards Association, which is now the American National Standards Institute [ANSI]) specifically designed for the general population which occupies residential, institutional and commercial environments. Its latest standard on this subject is "Ventilation for Acceptable Air Quality," ASHRAE Standard 62-1981 (8). This, and the earlier Standard 62-73, are the basis for most building codes on ventilation. These standards are based upon research, past practices and professional judgment. ASHRAE recognizes the developing state of research, and is now revising the standard.

Recently, widespread indoor concerns with specific pollutant concentrations have led to government indoor regulations on ozone (FDA) (18), asbestos (EPA) (19) and OSHA (15), and formaldehyde (HUD) (20). Others are being contemplated.

Considerable additional attention needs to be given to the development of standards for general indoor environments.

CONTROL METHODS

Control methods are important means of mitigating indoor pollution problems. As mentioned earlier, there are five basic methods for lowering concentrations of indoor pollutants:

1. Ventilation is the most commonly used method for controlling indoor

pollution. Usually it is employed so as to dilute the indoor air with quantities of outdoor air which are presumed to be less contaminated and also to exhaust polluted air. In buildings with mechanical ventilating systems, outdoor air quantities are provided by design, and the equipment operated insofar as practical to bring in outside air at rates specified in the applicable building codes. In these cases, near perfect internal mixing is assumed. In other cases, local exhaust may be employed to attempt to remove contamination near its source, such as in restroom exhaust systems. In residences and other locations where mechanical ventilation is not usually available, dilution is accomplished by natural leakage through cracks, windows and other openings in the envelope. This mechanism is highly variable, with wind, temperature differences and structural qualities playing significant roles. Codes presume the leakages to be adequate under ordinary conditions.

2. Removal of pollutants with special air treatment devices is employed where specific problems exist, or are thought to exist, and practical devices are available. Particulate filtering is a highly advanced technology, but increased performance involves higher equipment costs. Ordinary furnace filters are not effective in removing the respirable suspended particulates (RSP), but are effective with pollen and other large particles. High performance media filters and electronic filters are available at higher cost, and can remove from 80 to nearly 100% of the respirable particles. However, with practical ventilation systems, even a very efficient filter can only reduce indoor RSP levels to about 10-20% of those which would exist using common furnace filters (21).

Vapor and gas removal equipment is also available, but the technology for general use in ordinary occupied spaces is not well-advanced. Activated charcoal filters are used to adsorb high molecular weight gaseous molecules. It is difficult to determine when the filters are loaded, except by odor response of the occupants. As the filters become loaded, they also desorb the lighter molecules previously adsorbed, and this can be a problem. Activated charcoal filters are widely available, in varying efficiencies and holding capacities at costs in relation to their performance.

Potassium permanganate and other chemicals are available, impregnated into porous alumina pellets. The chemicals can oxidize or otherwise change some gases and vapors into other, less hazardous or odorous forms.

Other chemicals, used as "odor counteractants" have not been technically proven to be effective.

3. Exclusion of offending materials from indoors is an obvious control method. However, much work is necessary to identify all such materials and to provide satisfactory substitutes. Such materials include paints and other finishes, manufactured wood products, plastics, cleaning and maintenance materials, etc. Also included are a multitude of manufacturing processes that may be used to lessen the outgassing of some undesirable materials.

4. Encapsulation or coating materials, or otherwise interfering with the materials' ability to off-gas pollutants is another control strategy.

5. The activities of building occupants is another control strategy. If people are educated as to the effects of pollutants, they could act in ways to mitigate their personal exposure. Opening windows and minimizing the use of possible pollutants indoors are examples. This strategy relies on eduction of many individuals, and may be difficult.

While it is seen that many control strategies are available, the cost-effectiveness in practical applications is not well known, and much research remains to be performed on the existing strategies, and to develop new ones.

RESEARCH STATUS OF SOME POLLUTANTS

It is not possible to cover all the research done to date, but it is felt useful to identify some of the important pollutants, and to briefly summarize the research status of each. Each pollutant is described. Its sources and, where not obvious, its entry into the indoor environment are covered, as well as the geographical distribution and the general type of structure in which it is important. Existing standards and guidelines relevant to each pollutant are mentioned. The comfort and health effects of the pollutants are categorized in three ways. The first is annoyance; i.e., the pollutant can be perceived by occupants as not desirable. The second is an acute effect resulting in symptoms of respiratory tract dysfunction or other short-term disease. The third is a chronic or long-term effect, which may take decades to produce, such as lung cancer, emphysema, and heart disease. The state of measuring instrumentation is then covered. Current knowledge concerning mitigation techniques is treated, followed by a summary of suggested future research.

Radon

Description - Radon is a radioactive gas, the first decay product of Radium-226. It is an alpha particle emitter with a half-life of 3.6 days. It decays further into solid alpha emitters which can become attached to dust particles and surfaces in the environment and become lodged in the lungs (22).

Sources - Radium is ubiquitous in the earth's crust in widely varying concentrations. Well water and natural gas in some locations have high concentrations of radon. In some specific cases (2) masonry building blocks have high radium concentrations. The earth around buildings is the principle source, and radon penetrates cracks and drain openings in foundations, into basements and crawl spaces. Water containing radon will outgas into spaces when drawn for use indoors. Some building materials will outgas radon, some of which may enter buildings.

Location and Type of Structure - Geological studies have indicated geographic areas of high radon concentration in soils and water (4), and much attention has been given to these areas. It is not possible, however, to predict which subgroup of structures will have problems, due to the many other factors involved, such as the fill variations around buildings and foundation tightness. Radon is associated primarily with low-rise residential dwellings with concentrations generally being higher in basements than in upper floors (22).

Standards and Guidelines - Several standards and guidelines exist.

Organization		Radon level above which mitigating action is indicated, picocuries per liter (pCi/L)
U.S. Mine Safety and Health Administration (23) (for mines)		16
U.S. Bonneville Power Administration (of DoE) (23)	for residences and commercial buildings	5
EPA (23)	for residences and commercial buildings	4
ASHRAE Standard 62-1981 (8)	for residences and commercial buildings	2

Comfort and Health Effects - No sensory perception or acute health effects due to exposure to radon and radon daughters are known. The chronic effect is suspected to be lung cancer or other lung dysfunction due to retention in the lung of radon decay products. These chronic effects are among the best known of all indoor pollutants, as the result of studies on uranium miners for many years (24). The levels of radon are high compared to most buildings. It is speculated that non-occupational radon exposure in the U.S. may cause between 2,000 and 20,000 additional cancer deaths per year, and that one million U.S. dwellings have concentrations which may cause a significant risk to their occupants (7).

Measuring Instruments - Relatively inexpensive passive track-etch detectors (less than $50) are available for survey use, integrating radon concentration over a one- to three-month period. Air sampling instruments for real-time measurements (scintillation counters for example) are more expensive. No inexpensive method exists to measure radon daughter concentrations.

Mitigation Measures - Sealing of foundations to prevent entry has been demonstrated to be effective (25). Specific ventilation of basement areas and crawl spaces has also been shown to be effective (26). Increased ventilation with outdoor air will lower radon levels for a given building. However, radon levels do not correlate well with ventilation rates among different buildings (3). This is because source strengths of soil radon are quite variable. Therefore, increased ventilation cannot be relied upon to lower radon levels enough in all buildings where it is a problem.

Important Areas for Future Research - Needed are predictive models to assist in pinpointing problem structures; development of better cost-effective mitigation methods, devices, and materials; better building construction practices in radon-rich areas, as well as soil assessment methods prior to construction; and also better standards to guide economic mitigation measures.

Asbestos

Description - Asbestos is composed of small natural mineral silicate fibers widely used in insulation and other building materials until recently. The use of asbestos-containing spray-on materials is banned in U.S. buildings today (27).

Standards and Guidelines - There is currently no known "safe" concentration. The Occupational Safety and Health Administration (OSHA) is using a level is 0.1 fibers longer than 5 μm per cubic centimeter (f/cm^3) as the level above which abatement action must be taken (15). Currently there is discussion as to whether a level of 0.01 f/cm^3 may be more appropriate.

Comfort and Health Effects - No acute health or comfort effects are known. Fibers deposited in the lung are the only known cause of mesothelioma, a fatal cancer of the pleural or peritoneal area of the lung. Asbestosis and other lung conditions also have been identified (28). Extensive studies with asbestos workers have established the seriousness of these chronic problems (28).

Measuring Instrument - Phase contrast microscopy (PCM) is used as a screening method for sampling asbestos fibers in the air (15). A sample is collected on a membrane filter. Part of the filter is treated chemically to render it transparent. Particles are observed for shape and size, and the results are presented as f/cm^3 of 5 μm or longer. Fibers other than asbestos (e.g., glass, cellulose) are also counted (29). Electron microscopy is a method which can distinguish asbestos definitively, but it is much more expensive than PCM (29).

Mitigation Measures - Asbestos abatement in the U.S. is being handled as a special case separately from other air pollutants by U.S. agencies due to the perceived high public risk (15) (27). Reference 29 gives a more complete discussion of asbestos in buildings and suggested abatement guidelines. References 15 and 29 contain some regulations.

Areas of Future Research - Due to the time-varying nature of fiber release into the air caused by a number of activities in buildings, a better method of assessing the exposure of occupants is needed. Further determination of health effects of low exposure levels is needed. Measurement and abatement methods, which are now very expensive, need improvement.

Tobacco Smoke

Description - Tobacco smoke consists of solid particles, liquid droplets, and gases resulting from tobacco combustion. Particles of condensed combustion products are almost all in the respirable range, and over 2,000 specific materials have been identified in the particulates and associated gases (30).

Standards and Guidelines - No general levels have been agreed upon. ASHRAE Standard 62-1981 (8) specifies dilution with smoke-free air in quantities of 7-17.5 liters per second (L/s) per person, where smoking is permitted, depending upon the type of space. The standard is currently being revised but no significant change in these levels is now contemplated (30).

Comfort and Health Effect - Many people who do not smoke object to smoke in their environments as an annoyance (30). Tobacco smoke's health effect on nonsmokers (passive smoking) has had increased research attention recently (30). Its effects on smokers are well known. Acute health effects have been found in the lung function of children and spouses of smokers (31). Allergic reactions occur in a small fraction of the population. Some studies suggest that the chronic lung cancer risk of nonsmokers exposed to significant levels of smoke may be twice that of people who are not exposed to significant passive smoking (32).

Measuring Instruments - Particulate concentration is measured gravimetrically or by optical scattering of particles collected on filters. Gas chromatographs are used for gases. Enough work has been done so that reasonable estimates of the source strength can be made by simply counting smokers and knowing that about 30% of adults each smoke about two cigarettes per hour while awake (2).

Mitigation Measures - Prohibition of smoking in public spaces is becoming more common. Isolation of smokers is partially effective, but it usually also requires careful management of ventilation to be most effective (28). High efficiency air cleaners and gas filters are sometimes effective, if well applied and properly maintained. Increased ventilation is partially effective, but dilution in general spaces is often not totally effective, since very large ventilation rates are necessary to dilute smoke enough to be unobjectionable to most nonsmokers (4).

Areas of Future Research - Better quantification of health effects on nonsmokers; and development of more economical filter systems and ventilation strategies.

<u>Formaldehyde</u>

Description - Formaldehyde (HCHO) is a colorless water-soluble gas, which, due to its wide use and possible health effects, is such an important volatile organic compound (VOC) that it is considered searately.

Sources - Materials containing formaldehyde are widely used in buildings, furnishings, and consumer products. Urea-formaldehyde resins are used in the manufacture of plywoods, particleboards, and textiles. Some buildings have been insulated in the side walls with urea-formaldehyde foam insulation (UFFI). This product is banned in Canada and Massachusetts; unsuccessful attempts were made to ban it throughout the

U.S., but the resulting publicity has effectively closed that market. In the U.S., however, as many as 500,000 homes have been insulated with UFFI (14). Formaldehyde outgases from the above-mentioned products and has been a serious problem in many residences. Mobile homes have been particularly affected because of their small volume and the large amounts of formaldehyde-containing products found in them. Tobacco smoke and other combustion products are lesser sources. Indications are that time diminishes the outgassing from materials, so concentrations in spaces diminish with time. However, several years may be necessary to alleviate some problems.

Standards and Guidelines - There is much controversy concerning appropriate maximum levels for human occupancy. Scandinavian countries have established 0.1 ppm as a limit. ASHRAE has also included 0.1 ppm in its Standard 62-1981 (8), but the formaldehyde provision has yet to be made mandatory in building codes because of the controversy concerning possible health effects at these low levels. Some states in the U.S. have established 0.4 ppm in their codes for residences. In the U.S., the Department of Housing and Urban Development has developed a product standard for emission rates of plywood and other wood materials for manufactured housing (20).

Comfort and Health Effects - Formaldehyde has a pungent odor and is detected by many people at levels of about 0.1 ppm (31). Besides the annoyance, it also causes acute eye burning and irritates mucous membranes and the respiratory tract (14). Formaldehyde has also caused nasal cancer in laboratory animals, but the chronic effects have not been established for human beings (7). A number of people exhibit a high sensitivity to very small concentrations (14).

Measuring Instruments - Inexpensive passive samplers have been developed but their accuracies are not well established (3). Formaldehyde is extracted in a laboratory from a solid adsorbent in the passive samplers by water and the amount measured. The more traditional method of collecting formaldehyde is by impingers. Formaldehyde concentrations are usually determined by the pararosaniline or chromotropic acid methods. A third, the acetylacetone method, is less common (3).

Mitigation Measures - For problem UFFI cases, removal is indicated. The cost can be as high as $20,000 for a residence. Even then, residual materials may remain in the structure and continue to outgas. Increased temperature, humidity, and ventilation will accelerate outgassing. Some manufacturers are producing products with lower outgassing rates. Some surface treatments are being used to seal against outgassing, but these are still being studied.

Areas of Further Research - Both the measurement methods for formaldehyde and the calibration of these methods needs research. Product standards to limit outgassing need further development and application. More practical remedial measures for use in existing buildings are needed. Better material outgassing characteristics and models are needed.

<u>Nitrogen Oxides</u>

Description - The two most prevelant oxides of nitrogen are nitrogen dioxide (NO_2) and nitric oxide (NO). Both are toxic gases with NO_2 being a highly reactive oxidant, and corrosive. The NO gradually reacts with the oxygen in the air to form NO_2.

Sources - The primary sources indoors are combustion processes, such as unvented gas ranges, other unvented heaters, and tobacco smoke. Unvented heaters are experiencing increasing residential use in the U.S. due to their perceived energy-saving potential.

Standards and Guidelines - None have been agreed upon for indoor air. The U.S. National Ambient Air Quality Standards lists 100 $\mu g/m^3$ as the long-term (8 hr) limit (9).

Comfort and Health Effects - Oxides of nitrogen have no sensory effect in low concentrations. Acute effects of lung dysfunction have been reported at higher concentrations. Chronic effects are not well established.

Instrumentation - Small passive NO_2 monitors suitable for field use are available (3).

Mitigation Measures - Venting the NO_2 source to the outdoors is the most practical measure for existing conditions. Limited exposure to sources through behavior modification could be of some benefit to health. Manufacturers are developing devices having lower NO_2 generation.

Area of Future Research - Better methods of predicting where problems exist and the development of more practical mitigation measures are needed.

Other Volatile Organic Compounds (VOC)

Description - There are hundreds of other volatile organic compounds that are found in the indoor air, sometimes in concentrations which are suspected of being harmful. Those listed below are examples, but are not a complete list.

Compounds	Sources
acetone alcohols acids	effluents from peoples' metabolism
aromatic hydrocarbons chlorinated hydrocarbons organophosphates	various combustion processes pesticides
chlorinated compounds acetone ammonia toluene benzene	building materials personal care products, cleaners, paints, etc.

Measuring Instruments - Gas chromatographs are used for laboratory and some field studies. No inexpensive monitors suitable for extensive field use exist, but adsorbers can be used for later laboratory analysis.

Standards and Guidelines - None have been set for non-industrial indoor air. NIOSH (13) has recommended occupational standards for many compounds. ASHRAE Standard 62-1981 (8) includes a rationale suggesting that in the absence of better data, the NIOSH limits be divided by 10, to account for the possible continuous, rather than workplace, time of exposure and, to account for the elderly, young and infirm in the general population compared to the generally healthy working population.

Comfort and Health Effects - Several of these compounds have been identified individually as causing acute and chronic effects at high concentrations (13). Some cause cancer. The effects of combinations of these compounds at low concentrations have been suggested as causes of several "sick building" situations (2).

Location and Type of Structure - These are widely distributed in all building types.

Mitigation Measures - Where practical, uses of these sources should be restricted and these materials should be stored in well ventilated areas apart from occupied zones.

Areas of Future Research - Determination of the health effects of combinations of VOCs at low concentrations found in buildings is a need. Inexpensive sensors would also be useful. Practical removal hardware and other control devices are needed. Studies of substitute material compositions for lower emissions are needed.

Carbon Monoxide

Description - CO is a colorless, odorless, and tasteless gas. It results from incomplete combustion of carbon in fuels and is almost always accompanied by NO_x.

Sources - Any incomplete combustion which might arise from gas ranges, unvented heaters, leaky wood and coal stoves, and tobacco smoke may cause high concentrations in inside air. Only worn or poorly adjusted and maintained combustion devices seem to be significant sources. Automobile exhaust may enter houses from attached garages or enter buildings built over garages or near busy trafficways.

Standards and Guidelines - The U.S. National Ambient Air Quality Standards lists 40 mg/m^3 as the one-hour limit (9).

Comfort and Health Effects - Acute affects are due to the formation of carboxyhemoglobin in the blood, inhibiting oxygen intake. In moderate concentrations, cardiovascular disease, impaired vision, and loss of brain function may results. At higher concentrations it is fatal (4). CO is a serious problem in dwellings in developing countries due to extensive use of unvented combustion sources for heating and cooking.

Instruments - Some relatively high-cost infrared-radiation absorption instruments exist. Some moderately priced ($50) small real-time measuring devices are also available.

Mitigation Measures - It is most important to be sure appliances are clean and properly adjusted. Automobiles should not be run for extended period in attached garages. Additional ventilation can be used as a temporary measure when high levels of CO are expected for short periods of time.

Areas for Further Research - CO and its perils have been well known for a long time and public awareness is high. A low-cost alarm system is needed which could save some of the CO-related deaths.

Carbon Dioxide

Description - CO_2 is an odorless, tasteless, and colorless product of completed carbon combustion.

Sources - All combustion processes and metabolic processes are CO_2 sources.

Location and Type of Structure - In buildings, higher CO_2 concentrations are primarily associated with residences since unvented combustion is not usually permitted in other buildings. Low concentrations of CO_2 from people and smoking are always present in all buildings.

Standards and Guidelines - NASA maintains CO_2 levels of 1% or less for space environments, and U.S. submarines operate at 0.7% or less, indicating that young people in good health can perform without hazard at these levels. World Health Organization (WHO) guidelines (33) are 0.5% for indoor air and ASHRAE Standard 62-1981 (8) sets 0.25% as the upper limit. The outdoor level is usually 0.03%. Indoor concentrations are usually in the range of 0.1%.

Comfort and Health Effects - At concentrations above 1% in air, some loss of mental acuity has been noted. No major comfort or health effects in buildings have been noted because measured building levels are well below 1%.

Measuring Instruments - Instruments exist which are reliable and inexpensive enough for some commercial ventilation applications.

Area for Further Research - CO_2 has been proposed as an indicator of general air pollution problems and body odors when human occupancy is the major cause of pollution. But as is seen in this report, many other important pollutants which are not related to human occupancy can often be present. CO_2 control has also been tested experimentally as a "people-counter" in buildings to control ventilation proportional to the occupancy as an energy-saving strategy. Lower cost sensors and more field demonstration are needed.

Microorganism And Allergens

Description - Biological material, bacteria, viruses, mold spores, pollens, insect parts and feces, house dust mites, etc. are ubiquitous in indoor environments. These particulates range from less than one to several m in size. When airborne, they are usually attached to dust particles of various sizes so that all sizes of airborne particulates may include them.

Sources - People and pets "shed" such materials. Indoors, bedding, carpeting, and other places where dust collects can harbor them. Cooling towers have been known to be incubators of Legionella. Dirty air-conditioning equipment, humidifiers, condensate drains, and ductwork can incubate bacteria and molds (2). High humidity areas exacerbate their growth.

Standards and Guidelines - No standards for general indoor air applications exist. Cooling tower treatment procedures to reduce the levels of Legionnella and other organisms do exist (34).

Comfort and Health Effects - Tuberculosis, measles, small pox, staphylococcus infections and influenza are known to be transmitted by air as is Legionnaires disease (28). Upper respiratory disease, causing each person an average of about four days restricted activity per year, is a large economic cost associated with airborne transmission of disease (28). "Indoor airborne viruses and bacteria are the most important cause of acute disabling illnesses in the U.S." according to Hinkle (35). Pollens, molds, etc., cause allergic reactions for a significant portion of the population.

Measuring Instruments - Air samples can be collected on filters or impactors and incubated for visual examination of viable growths. Microscopic examinations of collected dust can be used to identify molds and pollen. No inexpensive field monitors exist which are suitable for large-scale use. Coated microscope slides and Petri dishes, which collect settled particles for laboratory analysis, have limited utility in surveys.

Mitigation Measures - General good housekeeping and maintenance of heating and air-conditioning equipment are important. Adequate ventilation and good air distribution also helps. High-efficiency air cleaners remove viable particles along with other particulates.

Areas for Further Research - The relationship of concentration of pathogens in the air to disease transmission is not well established. More economical air-treatment devices are needed, as well as better understanding of the roles of housekeeping and air-conditioning system maintenance.

COMPREHENSIVE INDOOR AIR QUALITY RESEARCH STRATEGY (7)

This report (7), mentioned earlier, describing a government-wide research strategy, is now summarized since it is the current coordinated proposal of future needed Federal research. It also includes suggested research contributions from state and local governments and the private sector.

The strategy aims at two objectives.

1. To develop an understanding of the magnitude of the risk to human health from exposures to indoor air pollutants, and the contribution of various energy conservation measures, introduction of new building materials and consumer products.

2. To provide technical information and guidance, including cost-effective mitigation measures, to state and local governments, the private sector and the general public.

Major Tasks

To accomplish these objectives, the following six tasks were identified as critical elements of the strategy. These tasks form the basis of this research strategy, and are interrelated. In addition, they are consistent with the recommendations expressed by non-Federal groups, WHO, NAS, ASHRAE, and others. Accomplishment of these tasks requires an integrated effort.

1. Identification of indoor air pollutant sources and factors affecting human exposure.
2. Characterization of indoor air quality.
3. Determination of the relationship between energy conservation and indoor air quality.
4. Determination of the health effects of indoor air pollution.
5. Determination of optimal control and mitigation techniques.
6. Development and conduct of national multipollutant field studies.

Current Federal Research on Major Tasks

Task #1: Identification of Indoor Air Pollutant Sources and Factors Affecting Human Exposure

The identification of significant sources of indoor air pollutants (Table 1), their migration pathways and environmental factors that influence human exposure provide the basis for the interpretation of monitoring data and the development of cost-effective control technology. To date, a high priority has been placed on the basic phenomena that affect human exposure for radon, formaldehyde and other organics, and combustion pollutants.

Efforts to determine the sources and dynamics of indoor radon are directed to:

1. Determining the contributions of soil, water, and building materials to the indoor radon source term;
2. Developing models that relate indoor radon concentrations to the various sources, migration pathways, driving forces, and air infiltration rates;
3. Determining environmental factors, such as building construction, particulate concentrations, temperature, pressure, humidity, and human activity patterns, that influence human exposure to radon and its decay products; and
4. Determining the radiation dose to the respiratory tract from the inhalation of radon decay products.

Table 1: Typical Sources of Indoor Air Pollutants[1]

Sources	Pollutants
Ambient Air	Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_x), Ozone, Carbon Monoxide (CO), Particulates, Organics, Metals
Soil	Radon
Water	Radon, Volatile Organics
Combustion Engines	NO_x, CO, CO_2, Organics, Particulates, Metals
Building Materials	
Concrete, Stone, Brick	Radon
Pressed Wood products	Formaldehyde, Other Volatile Organics
Insulations	Formaldehyde, Fibers, Asbestos[1]
Adhesives, Paints and Solvents	Volatile Organics
Air Conditioners, Humidifiers	Bacteria, Fungi, Protozoa
Combustion Appliances (gas, wood, coal, oil and kerosene)	NO_x, CO, CO_2, Water Vapor, Organics, SO_2, Particulates
Furnishings	Formaldehyde, Other Volatile Organics, Fibers
Office Machines and Supplies	Organics, Particulates, Ozone
Cleaners and Polishes	Ammonia, Volatile Organics, Particulates
Human	
Metabolic	CO_2, Odors, Water Vapor, Bacteria
Smoking	CO, CO_2, NO_2, Organics, Particulates
Cooking	Organics, Odor, Water Vapor
Hobbies	Organics, Microorganisms
Hygiene	Organics, Odor
Animals and Pests	Microorganisms, Mites, Allergens, (animal dander, insect parts and feces)
Plants, Microbial Contamination	Spores, Pollen, Allergens

[1]Asbestos research is not discussed in this strategy, because Federal research and regulatory action are coordinated through the Federal Asbestos Task Force.

Research on organic pollutants is directed toward determining the contribution of various building materials as chronic sources of airborne pollutants, including formaldehyde. The relationship between pollutant emissions from building materials and building-related factors such as construction techniques, ventilation, temperature, humidity and age of the material are being studied. Consumer products and structural sources of various organic compounds identified indoors are also being evaluated.

Studies are in progress to determine the emission properties and major pollutants of combustion sources such as unvented kerosene and gas heaters and coal/wood stoves. The influences of appliance design, ventilation and use patterns are included in this research.

Task #2: Characterization of Indoor Air Quality

Earlier studies which characterized indoor air pollutants were limited in scope because they used small sample sizes, measured only single or few pollutants, studied a single source, were conducted in a limited geographic area or used different methodologies. Though valuable in their context, these data do not provide a unified national picture of indoor air pollution. Therefore, a national multi-pollutant field survey would provide the data base required to develop hypotheses and further test and determine dose-response relationships. However, before conducting such a study, there must be an effort to:

1. Develop instruments to monitor pollutants and gather other relevant data;
2. Field test these instruments for efficacy, reliability, and cost-effectiveness;
3. Develop analytical tools and models; and

4. Centralize this information where interested parties can have access to it.

Current Federal research which supports these efforts is summarized below:

Methods Development - Research to develop passive samplers for CO, NO_2, CO_2, volatile organics, water vapor and air exchange rates is in progress. Simple cost-effective active sampling techniques for CO, NO_2, formaldehyde, and organic vapors are being evaluated.

Field Monitoring Studies - Both existing and new methodologies are being tested for appropriateness and cost-effectiveness in pilot studies.

Analytical Methods and Models - Mathematical models are being developed to relate indoor pollutant concentrations to pollutant sources, removal mechanisms, thermal comfort parameters, and air exchange rates. These models will be used to predict indoor air quality and associated health effects in indoor environments, to simulate the effects of proposed mitigation efforts, and to perform cost-benefit analyses. The models will be validated and verified by field data.

IAQ Data Base - To maximize analysis and distribution of information to interested Federal and local agencies and the private sector, uniform data formats are needed. Results from past field studies are being compiled for entry into a single data base. Results from current and future field studies will also be entered into this data base.

Task #3: Determination of the Relationship Between Energy Conservation and Indoor Air Quality

Energy conservation and indoor air quality requirements will have important ramifications on the cost, design and operation of comfort conditioning systems, energy use patterns and peak energy usage.

The growing trend in new construction is substantially reduced infiltration. For residences, typical levels of about 0.7-1.0 air changes per hour may be reduced to as low as 0.1 to 0.2 air changes per hour. When infiltration is reduced to this extent, elevated levels of indoor pollutants will be found. More research is required to relate ventilation rates to indoor air pollutant concentrations and to provide for the establishment of energy efficient ventilation guidelines which maintain acceptable indoor air quality.

Infiltration and Ventilation - Research efforts devoted to infiltration and ventilation studies in residential buildings have contributed significantly to the development of infiltration measurement techniques, air leakage characterization of buildings, and infiltration models to assess the impact of reduced infiltration rates on energy requirements and indoor air quality. Current research includes:

1. Extending single chamber, residential infiltration models to include all forms of ventilation (both natural and mechanical);
2. Developing and validating low cost methods of measuring infiltration and leakage, (e.g., passive perfluorocarbon tracer gases techniques and acoustic AC pressurization);

3. Testing a multi-chamber infiltration model suitable for multi-family residential buildings and multizone single-family buildings; and

4. Participating in national and international efforts to develop ventilation, leakage, infiltration, and construction quality guidelines.

Only very limited information exists on infiltration and ventilation in commercial and institutional buildings. Research is required to develop and validate techniques to measure ventilation rates and air distribution patterns. Prototype systems are being developed which utilize multiple tracer gases, both actively and passively. Research efforts will test and validate these systems. Data on ventilation rates and efficiencies are being collected in a number of commercial buildings and will be used to extend the multichamber infiltration models described above.

Combustion Appliances and Building Materials - Research on supplemental heating appliances has included field studies, laboratory chamber studies of pollutant emission rates, consumer use surveys and limited exposure modeling. Current efforts concentrate on development of certification test methods and voluntary guidelines for these appliances.

Formaldehyde emissions from urea-formaldehyde foam insulation, pressed wood products and fibrous glass insulation have been characterized and evaluated. This information has been provided to manufacturers and to consumers for their consideration in development of voluntary guidelines. In addition, volatile organic emissions from building materials, such as sealants and caulking compounds, are now being investigated.

Task #4: Determination of Health Effects of Indoor Air Pollution

Occupational and residential studies of most indoor pollutants have not produced adequate data to determine specific health effects and exposure-response relationships for pollutants found in indoor air. Only limited data are available to define the acute and chronic health effects from low level exposures to essentially all of the indoor air pollutants. Generally, such effects are extrapolated either from occupational exposure studies or from animal toxicity studies. Animal toxicity studies are in progress on some indoor air pollutants, (e.g., perchloroethylene, dichloromethane, formaldehyde, and nitrogen dioxide).

Controlled human exposure studies have been initiated to obtain exposure-response relationships for specific acute health effects from exposure to pollutants. Such studies include responses of sensitive individuals (e.g., asthmatics) exposed to irritant gases such as nitrogen dioxide, formaldehyde, and sulfur dioxide. Additional studies have been initiated to develop biochemical markers of exposure to specific pollutants and pollutant sources. These markers may prove useful in future epidemiological studies.

Health hazard evaluations are documenting exposures to low levels of numerous air contaminants, such as volatile organics. Incidents of adverse health effects are also being reported in commercial and institutional buildings from exposure to volatile organics, sidestream tobacco smoke, fibers, biologically active aerosols, and allergens. Additional studies in progress may provide further information on such associations.

Discussions are underway between EPA and the National Center for Health Statistics (NCHS) on utilizing the National Health and Nutrition Evaluation Survey III (NHANES III), planned in fiscal year 1988, to determine adverse health effects associated with exposure to indoor air pollutants.

Task #5: Development of Effective Control and Mitigation Techniques

Mitigation and control research is being pursued for the commercialization of energy efficient techniques to control indoor pollutant concentrations. Current efforts include evaluating techniques to reduce pollutant strengths and block migration pathways, examining pollutant-specific removal mechanisms, and studying ventilation processes in indoor environments.

Ventilation strategies, with and without heat recovery, air purification devices, and architectural and material applications are appropriate in some situations. The effectiveness of these mitigation measures is being laboratory tested, evaluated, and mathematically modeled.

Pilot mitigation programs are being developed to test a range of approaches for reducing excessive concentrations. The objective of these studies is to assure the effectiveness of mitigation measures in wide-scale mitigation programs. Mitigation measures are being studied as a function of building characteristics, appliances used, and occupant use patterns.

The results of control and mitigation research efforts will be used to develop consensus testing protocols, guidelines, and information for developing voluntary standards, primarily by industry itself. Pilot mitigation program results will be made available in reports to state and local agencies, utilities, and other groups interested in mitigation.

Task #6: National Multipollutant Field Survey

A large national multipollutant field survey of indoor air pollution will be a key component in the research program. The National Multipollutant Field Survey will provide the data base required to develop hypotheses to determine dose-response relationships. The survey will draw upon the results of the previous research tasks, and survey results will focus future research in these ongoing efforts. The survey will provide an estimate of the range and distribution of indoor exposures to indoor air pollutants, and identify those factors which influence their concentrations. The impact of energy conservation practices, including reduced ventilation rates and use of supplementary heating sources, and the effectiveness of mitigation techniques will be studied. A National Multipollutant Field Survey is necessary to identify and focus further indoor air quality research efforts, to control indoor air pollution and to assess the impact of future energy conservation.

The Field Studies Workgroup of the CIAQ will direct the planning, development and execution of this national survey. Over the next year, this Workgroup will coordinate the development of sample design options for a national survey, taking into account the research on factors affecting exposure levels of specific indoor air pollutants (e.g., climate, pollutant sources, ventilation). The Workgroup will also evaluate and coordinate the CIAQ agencies' research efforts in field testing and participation in regional indoor air quality studies. These coordination efforts will help ensure that this Federal research effort will provide the necessary basis for conducting a national field survey.

The Field Studies Workgroup will also review current health studies, and recommend various options for obtaining health effects information, including a possible joint survey in conjunction with the NCHS NHANES III study.

By the end of 1985, the Workgroup plans to present various options for a national indoor air field survey to the full CIAQ for review and implementation.

Future Research Needs of the Major Tasks

Current federally sponsored research is addressing, in a limited way, each of the six previously identified tasks. Because of the nature of the indoor air pollution problem, a much more comprehensive program is required by both the public and private sectors. The following strategy is directed at overall program needs, with the CIAQ and its workgroups providing a central coordinating function in the development process. Federal agencies will collaborate in the development and accomplishment of this program according to their missions, expertise, and budgetary capacity.

Each of the six research tasks discussed previously is essential to the definition of current and future trends in indoor pollutant exposure, the consequent risk, and the most effective mitigation techniques. In addition to the current research tasks described in the previous sections, the following research needs must also be pursued.

Task #1: Sources and Environmental Factors Affecting Human Exposure

- Initiate research efforts to identify and quantify sources of indoor allergens and organic compounds

- Expand efforts to quantify sources and pathways of combustion products, radon, and formaldehyde
- Investigate environmental factors (e.g., air exchange rates, structural characteristics) affecting occupant exposures to indoor air pollutants

Task #2: Characterization of Indoor Air Quality

- Methods Development and Field Testing

  Develop monitoring instrumentation, both active and passive, for volatile organic pollutants, allergens, microorganisms, particulates, NO_2 and CO

  Refine, field tests, and transfer to the commercial market instrumentation for all of the above

  Develop survey questionnaires and protocols

- Quality Assurance

  Develop quality assurance programs, similar to that in place for radon, for the important chemical and biological pollutants to assure that exposure measurements made by various laboratories in the United States and elsewhere are comparable

- Analytical Methods and Modeling

  Develop standardized techniques for data analysis that assure validity and accuracy

Improve and validate existing multipollutant indoor air quality models

- Data Base

  Expand data bases to include measurement technologies and health effect surveys

Task #3: Impact of Energy Conservation

- Develop predictive models for determining the effects of building design and energy conservation practices on future indoor pollution exposures
- Refine passive samplers for multi-zone infiltration and ventilation studies
- Continue development of techniques to perform air infiltration, ventilation, and ventilation effectiveness measurements in commercial and institutional buildings

Task #4: Health Effects

- Conduct chronic toxicity studies on laboratory animals
- Study populations particularly sensitive to chemical or microbial indoor air pollutants
- Develop biochemical markers for exposure to pollutants, (e.g., urinary cotinine for passive tobacco smoke and urinary hydroxylproline for NO_2)
- Evaluate the toxicity of low level exposure to particulates and other chemicals both individually and in combinations
- Develop and conduct appropriate epidemiological studies for indoor pollutants, (e.g., radon and formaldehyde)

- Utilize more sophisticated approaches to study the health effects of pollutants such as NO_2, CO and formaldehyde
- Evaluate the use of CO_2 in large buildings to predict complaints of tight building/sick building syndrome

Task #5: Pollutant Control

- Develop and evaluate source control and mitigation measures for risk reduction and cost effectiveness for a broad range of indoor environments and pollutants
- Validate minimum ventilation requirements to support consensus guidelines designed to provide acceptable health and comfort levels in indoor environments.

Task #6: National Multipollutant Survey

- Develop and conduct a multipollutant field survey to determine the national distribution of indoor exposures and associated health effects
- Utilize survey results to design and conduct specific studies to obtain additional information about health effects, energy conservation, pollutant sources and control options

In summary, a major national effort is needed to implement this comprehensive indoor air quality research strategy. Action is needed by both the public and private sectors! The CIAQ's role in addressing this problem will be to coordinate Federal research efforts, and to develop new mechanisms for interacting with state and local governments and the public and private sectors. Through the CIAQ workgroups, research conducted in other programs, such as the National Toxicity Program, will be used to augment indoor air quality efforts. The CIAQ will also periodically evaluate research results to reassess health risks associated with indoor air pollution. Finally, the CIAQ will make a concentrated effort to assure technology transfer through dissemination of research results and participation in symposia, public meetings, and workshops.

NBS COMPETENCIES IN INDOOR AIR QUALITY RESEARCH

Under its general mission of developing and supplying technical data, standard reference materials, evaluation methods and measurement methods, several centers of NBS have expertise needed to further indoor air quality research. Several are currently contributing, and have contributed to programs supported by EPA, DoE, CPSC and others. Listed below are some Centers and Divisions which have expertise. These NBS capabilities listed are those included in the CIAQ research strategy as future needs.

Center for Analytical Chemistry
Gas and Particulate Sciences Division
Organic Analytical Research Division

- Sensor R&D, including personal monitors,
- Standard pollutant concentration reference materials,
- Standard field sampling protocols
- Pollutant concentration measurement methods

Center for Chemical Physics

- Methods of source emission determinations
- Dioxin formation and modeling

Center for Radiation Research

- Radon measurement methods
- Radon concentration reference materials
- Radon emanation from materials

Center for Building Technology

- Infiltration rate measurements
- Indoor air flow measurements
- Ventilation system measurements

} Tracer gas measurement systems and methods

- Ventilation effectiveness measurements
- Air movement measurements
- Development of models of building systems for predicting contaminant levels outside-to-inside and room-to-room)
- Validation of models
- Air cleaner performance evaluation
- Combustion appliance emanation rate measurements
- Emanation rate measurements from materials

Center for Fire Research

- Combustion products emanation rate measurements
- Smoke migration measurements within and between spaces
- Modeling of inside pollutant concentrations from fires and model validation.

SUGGESTED NBS ROLE

The role of NBS in supporting research in the area of IAQ should remain within the general NBS mission. Health effects determinations are a vital part of the necessary research, but are not in the NBS mission. Many competencies exist outside NBS which overlap the NBS mission, so it is unrealistic to expect NBS to obtain an exclusive mandate for all IAQ work within its mission. There are many specific areas where NBS is uniquely qualified, and these should be stressed. Field measurements are an important need of IAQ. NBS work on field measurements is best done in support of instrument development and validation work and to develop suggested field protocols. Specific areas where NBS has a partial and sometimes unique role are listed below:

- Standard concentration reference materials

- Sensor and instrument development for sampling

  organics
  particulates

  radon

  inorganics

- Analytical methods for air sampling

organics

radon and daughters

heavy metals and other inorganics

- Certification of instrument system accuracy
- Concentration modeling in complex systems in both micro and macro environments
- Tracer gas methods for all kinds of ventilation measurements
- Pollution emanation rate measurement methods and data collection

RECENT CBT RESEARCH ON INDOOR AIR QUALITY

In FY 1984, CBT had six projects which can be included as IAQ or IAQ related. The NBS funded projects are listed:

1. IAQ in Office Buildings.
2. Expert System for Diagnosis for Air Leakage
3. Large Building Air Movement

In addition, DoE funded two projects:

1. Urea-Formaldehyde Foam Insulation Summary and,
2. Wall System Air Leakage Research.

and CPSC funded one project:

1. Pressed Wood Model Evaluation

These projects are briefly summarized in Appendix A. The total effort was $421.5K.

In FY 1985, DoE continues to fund one project:

1. Infiltration Measurements in Large Buildings.

CPSC continues funding of one project:

1. Pressed Wood Model Evaluation.

And EPA funding was received for one project:

1. Indoor Air Quality Modeling

and EPA also helped fund the Pressed Wood Model Evaluation project.

The total funding for the FY 1985 projects is $331.25K. This is a decrease from FY85. However, it should be noted that the entire amount is funded by other agencies. These projects are summarized in Appendix B.

OUTSIDE FUNDING POSSIBILITIES FOR FY86

EPA had $2M for IAQ in FY 1985. EPA expects to have $3M for FY 1986, but congress has not yet acted on its budget. NBS has received FY 1985 EPA funding, with increased funding expected to continue in FY 1986 and 1987.

CPSC has a nearly $2M, and also funded CBT in FY 1985. This funding is expected to continue in FY 1986.

DoE has funded CBT research for many years. DoE had approximately $1.7M in FY 1985 to perform IAQ research related to its energy conservation functions. CBT had FY 1985 funding and a larger amount is also expected for FY 1986.

NBS internal funding in the amount of $96K has been received to develop some of the more basic elements of IAQ modeling work and to help position CBT's technology to be even more useful to OA sponsors in this important national problem.

EXPECTED CBT RESEARCH IN FY86

Although a FY86 funding is not altogether firm, indications are strong that five projects will be funded. They are summarized in Appendix C. That expected funding totals $657.25K. It is expected that some additional projects may also be funded during FY86.

CBT RESEARCH PLAN

The CBT plan will build upon the IAQ work to date. In implementing and executing the plan, CBT will cooperate with other NBS units wherever appropriate. Several proposals have been developed by CBT divisions which show the capabilities and interests in indoor air quality. These proposals are not yet funded, but have been discussed within CBT and with EPA, DoE and CPSC as appropriate. They are summarized in Appendix D.

The new indoor air quality program was included in the CBT Long Range Plan in November 1984. It was revised in November 1985 in the National Research Council Board of Assessment Panel for Building Technology Vol. II. This plan is repeated below and should be the research plan for IAQ work in CBT. Since much of CBT's work depends upon other agencies, and other forms of outside support, the execution of the plan will depend largely upon outside funding, and CBT's vigorous proposal activities. Ranges of annual funding have been added to the milestone chart. These amounts could be efficiently employed.

Indoor Air Quality

Objective: To provide research and technical data to assist in standards development and control requirements, and to encourage new control developments.

To develop comprehensive indoor air quality (IAQ) models to assist standards development. Validate the models through laboratory and field research in ventilation, source emission, and control. Develop measurement systems for field and laboratory research and suggest new ventilation strategies.

Background: Several pollutants have been identified in dwellings, commercial buildings, hospitals, government buildings, etc., at levels above those considered to be appropriate in industrial workplaces. For example, high levels of radon, CO, formaldehyde, NO_2, tobacco smoke, and a wide variety of organic compounds have been measured. Health effects of an acute nature have been identified and chronic health effects have been suggested. Estimates indicate that as many as 20 million people may be at risk from airborne contaminants over their lifetimes.

The information to date suggests a serious and urgent need to understand and improve IAQ in the public interest.

CBT is uniquely qualified to address the interaction of IAQ control systems with the building HVAC system and the building envelope system so that better assessment of IAQ controls can be made in terms of energy impact, environmental changes affecting health and comfort, and life-cycle cost implications.

Technical Approach: CBT work will assist other agencies and the private sector in developing needed guidelines, standards, and technical data for improved IAQ through control strategies, equipment design, and building design. CBT will build upon its past leadership in developing complex models capable of predicting pollutant levels from sources introduced into buildings from outdoor air, and those generated inside from point sources, such as a gas range, as well as area sources, such as from floor and wall coverings. Several different models will be developed to predict indoor contaminant levels as functions of emission, dilution, intra-building movement, absorption, and settling. The internal mixing effects within rooms and between rooms will also be analyzed, as will the effects of infiltration and forced ventilation. The effect of internal air mixing and ventilation effectiveness will also be analyzed. The models will permit the evaluation of the effects of contaminant removal mechanisms, through interaction with the building materials and furnishings, control devices, ventilation strategies, and interactions with other indoor air contaminants. The completed models will enable accurate predictions of indoor levels of all important contaminants in all significant types and locations of structures so that appropriate control strategies can be developed. The models will be verified by using data from laboratory and field studies at CBT as well as from information obtained by other researchers. Sensitivity analysis is expected to suggest areas of specific research where additional knowledge is needed.

CBT will use its extensive capabilities in ventilation and infiltration measurement system development in residences and office buildings to evaluate ventilation strategies and controls, including heat recovery devices, suggest novel control strategies, and develop measurement systems for use by others.

The lead roles are with EPA, CPSC, DoE and NIOSH. CBT has demonstrated capabilities in thermal and ventilation modeling, and infiltration measurement, and has been called upon in these and many other related areas by these agencies.

Interactions: CBT has many effective methods of delivering its technical results to users. Interagency reports to sponsors are always written. CBT representation on the IAQ Interagency Committee is effective for coordination and delivery of research results. Many CBT professionals are active in ASHRAE and ASTM, which provide private sector technical programs of wide interest and reputation, as well as vigorous voluntary standards generation. These standards are widely used by governments at all levels. CBT research is also published in many other referenced documents.
Resources: CBT has been active in these areas in the past and will build on this work to provide a more comprehensive IAQ program. Further work in the period beyond five years will also be necessary. A total of 10 years is expected.

Staffing needs to be expanded to conduct a significant program. For expansion, two professionals with chemical background would be needed. The program will involve the Building Physits, Building Equipment and Building Materials Divisions.

MILESTONES

Planned Activities	86	87	88	89	90
	TIME TABLE				
Model Development	----	----	----		
Model Validation			----	----	----
Pollutant Characterization					
Formaldehyde	----	----			
Organic Contaminants		----	----	----	----
Field Measurements					
Ventilation Effectiveness	----	----			
Commercial Building Protocol	----	----	----		
Ventilation System Performance			----	----	----
Control Systems					
Air-to-Air Heat Exchange Test Method		----	----		
Particulate Air Cleaner Test Method		----	----	----	
Gaseous Air Cleaner Test Method			----	----	----
Effort					
Minimum	$700K	$750K	$800K	$800K	$800K
Maximum	$900K	$900K	$1000K	$1100K	$1100K

REFERENCES

[1] Moschandreas, D. J. and Morse, S. S.,; "Exposure Estimation and Mobility Patterns;" 72nd Annual Meeting of the Air Pollution Control Association; Cincinnati, OH; 1979.

[2] Proceedings of the Third International Conference of Indoor Air Quality and Climate; Swedish Council for Building Research; Stockholm, Sweden; August 20-24, 1984; Five volumes.

[3] "Indoor Air Pollution;" Environment International; Pergamon Press; 1982; Volume 8, Nos. 1-6.

[4] Indoor Pollutants; National Academy of Sciences; National Academy Press; Washington, DC; 1981.

[5] Spengler, J. D. and Steton, K.; "Indoor Air Pollution: A Public Health Perspective;" Science, July 1983; Volume 221, pp. 9-17.

[6] Turiel, I., Fisk,W. J., and Seedall, M.; "Energy Savings and Cost-Effectiveness of Heat Exchanger Use As An Indoor Air Quality Mitigation Measure in the BPA Weatherization Program;" Energy; 1983; Vol. 8(5); pp. 323-335.

[7] Indoor Air Quality Research Strategy; U.S. Interagency Committee on Indoor Air Quality; U.S. Environmental Protection Agency, Office of Research and Development; Washington, DC; December 1, 1984.

[8] Ventilation for Acceptable Indoor Air Quality; ASHRAE Standard 62-1981, American Society of Heating, Refrigerating, and Air-Conditioning Engineers; Atlanta, GA; 1981.

[9] National Primary and Secondary Ambient Air Quality Standards; U.S. Environmental Protection Agency, Code of Federal Regulations, Title 40, Part 50.

[10] Morey, P. R. and Runders, R. E.; Proceedings of the Third International Conference on-Indoor Air Quality and Climate; Stockholm, Sweden; August 20-24, 1984; Volume 3, pp. 247-252.

[11] ASHRAE Handbook, Fundamentals, Atlanta, GA, 1981.

[12] ASHRAE Handbook, Equipment, Atlanta, GA, 1983.

[13] Criteria for Recommended Standards, (Series); National Institute of Occupational Safety and Health, U.S. Department of Health, Education, and Welfare; various dates.

[14] Criteria for Recommended Standard -- Occupational Exposure to Formaldehyde; National Institute of Occupational Safety and Health, U.S. Department of Health, Education, and Welfare; Publication No. 77-125, References 57-93.

[15] Occupational Safety and Health Administration Asbestos Regulations, Code of Federal Regulations, Title 29, Part 1910.1001.

[16] Threshold Limit Values of Airborne Contaminants, American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

[17] American Industrial Hygiene Association, Community Air Guides, printed in the Association's Journal as indicated below:
Acrolein and Formaldehyde, AIHAJ 29(5): 505-512, Sept.-Oct., 1968
Beryllium, AIHAJ 29(2): 189-92, Mar.-Apr., 1968 Phenol and Cersol
AIHAJ 30(4): 425-428, July-Aug., 1969.

[18] Food and Drug Administration, U.S. Department of Health, Education and Welfare, Maximum acceptable level of ozone, Code of Federal Regulations, Title 21, Part 801.415 (21 CFR 801.415).

[19] Environmental Protection Agency Regulations for Asbestos, Code of Federal Regulations, Title 40, Part 61, Subparts A and B.

[20] Rule for Manufactured Housing Construction and Safety Standards, U.S. Department of Housing and Urban Development; Effective February 15, 1985.

[21] "Performance and Application of Electronic Air Cleaners in Occupied Spaces" P. E. McNall, Jr. et al ASHRAE Journal, May 1965.

[22] Radon in Buildings; National Bureau of Standards Special Publication 581; 1980.

[23] Home Weatherization and Indoor Pollutants; Environment and Power, Bonneville Power Administration, Department of Energy, E&P 3-7; September 1984.

[24] Archer, V. E. et al.; "Uranium Mining and Cigarette Smoking Effects on Man"; Journal of Occupational Medicine; 1973; Volume 15, pp. 204-211.

[25] MacLaren, J. "The Reduction of Radioactivity Found in Bancroft, Ontario and its Environs" Atomic Energy Control Board, Canada 1979.

[26] Fisk, W.J. et. al. "Indoor Air Quality Control Techniques: A Critical Review" Building Ventilation and Indoor Air Quality group, Lawrence Berkeley Laboratory, Berkeley, CA, Mar. 1984.

[27] National Emission Standards for Hazardous Air Pollutants, Code of Federal Regulations, Title 40, Part 61, Subpart M.

[28] "Symposium on Health Aspects of Indoor Pollution"; Bulletin of the New York Academy of Medicine; New York; December 1981; Volume 57, No. 10.

[29] Pielert, J. and Mathey, R.; Guidelines for Assessment and Abatement of Asbestos-Containing Materials in Buildings; NBSIR 83-2688; National Bureau of Standards; Gaithersburg, MD; May 1983.

[30] Smoking and Health; A Report of the Surgeon General, U.S. Department of Health, Education, and Welfare; Publication No. PHS 79-60066.

[31] Ferris, B. G. Jr., Dockery, D. W. and Ware, J.; Proceedings of the Third International Conference on Indoor Air Quality and Climate; Stockholm, Sweden; August 20-24, 1984, Volume 2, pp. 309-311.

[32] Trichopoulos, D., et.al.; Lancet II; 1983; pp. 677-678.

[33] Indoor Air Pollutants-Exposure and Health Effects Assessments; World Health Organization Working Group Report; Copenhagen, 1983.

[34] Mortality and Morbidity Weekly Report; Centers for Disease Control; Atlanta, GA; June 22, 1979; Volume 28, Number 24.

[35] Hinkle, L.E. Jr. and Murray, S.H.; "The Importance of the Quality of the Indoor Air"; Bulletin of the New York Academy of Medicine; New York; December 1981; Volume 57, No. 10, pp 827-844.

Appendix A - FY84 Project Summaries

1. Title: Indoor Air Quality in Office Buildings

Funding: $50K (NBS)

Objective: Determine general needs of commercial office buildings and the specific degree of space mixing in buildings and its effects on indoor air quality (IAQ).

Problem Significance: Commercial building problems have had little attention to date, but growing problems are emerging. Several buildings have been evacuated due to "building sickness syndrome," a term attached to poor air quality causing occupant complaints. In some cases, very little ventilation air was provided. In others, specific biomatter was multiplying in the HVAC systems, and affecting the occupants. The increased uses in buildings of materials which outgas are also suspected. Definitive IAQ standards and design practices are needed.

Technical Approach: Technical support was provided to other CBT projects. Work with EPA on their program reviews and with DoE and NIBS identified other specific needs. The focus was on measurement methods for indoor contaminants and ventilating systems for commercial office buildings. What should be measured? What measurement techniques should be used, etc.

Product in FY84:

1. Invited paper for Engineering Foundation Conference on Ventilation in Enclosed Spaces, titled "The Impact of Building Codes and Regulations on Indoor Air Quality." — 3/84
2. Invited paper for the American Conference of Governmental Industrial Hygienists on "Ventilation Concepts for Office Buildings." — 6/84

2. <u>Title</u>: Expert System to Diagnose Air Leakage Problems in Complex Buildings

<u>Funding</u>: $50K (NBS)

<u>Problem Significance</u>: Although air leakage plays extremely important roles for the transfer of heating/cooling energy, humidity and contaminants from one zone to the next, currently there is no adequate procedure to predict and control the movement of building air under naturally ventilated conditions and to diagnose air leakage problems in buildings. NBS has recently developed a sophisticated computer program called TARP to simulate simultaneous transfer of air, heat, moisture and contaminants on a dynamic basis. Presently the program is a research tool and not suitable for the use in design and control processes whereby the building envelope and HVAC system are to be optimized from the standpoint of indoor air quality, thermal environment and annual energy consumption. Introduction of the Expert System is needed to expedite the decision process.

<u>Technical Approach</u>: The first phase of this research program is to develop a frame work for using the concepts of the Expert System in building air algorithms in TARP for the development of decision processes for diagnosing air leakage and ventilation problems in complex buildings. Representation of air motion, its phenomenological characteristics as well as known physical principles, will be compiled into a knowledge data base, which can be used in the decision making algorithms.

<u>Products in FY84</u>:

1. "Expert Systems and Air Infiltration" 9/84

3. <u>Title</u>: Large Building Air Movement

<u>Funding</u>: $100K (NBS)

<u>Objective</u>: Develop predictive modeling and measurement methods for the air

movement in large buildings.

Problem Significance: Large buildings have complex air movement patterns. The understanding of these air movement patterns is required for the assessment of their energy performance, for the determination of indoor air quality, for understanding moisture migration and for smoke control. It is difficult to either analytically model this air movement or to experimentally measure the movement of air in multizone buildings.

Technical Approach: The NBS developed Thermal Analysis and Research Program (TARP) was used to predict the interzone air movement in several large office buildings in which NBS had measured the air infiltration and ventilation. The results of this analysis was used to design a field test to validate the prediction of TARP. The NBS developed automated air infiltration monitoring system for large buildings was used to measure the migration of a tracer from various zones of the building to adjacent zones. The results of these measurements will be used to validate the predictions of TARP.

Products in FY84:

1. "Air Flow Calibration of Building Pressurization Devices" 10/84

4. Title: Urea-Formaldehyde Foam Insulation

Funding: $50K (DoE)

Objective: The objective of this project is to provide a review of the technical issues concerning urea-formaldehyde foam insulation in walls and ceilings of residential construction. This includes a review of the properties and composition of these insulations and techniques for their measurement, a review of remedial measures such as foam removal to eliminate or reduce problems associated with its presence, and an identification of research needs to resolve the problems caused by urea-formaldehyde foam in residences.

<u>Problem Significance</u>: The Consumer Produce Safety Commission determined in March 1982 that urea-formaldehyde foam insulation presents an unreasonable risk of injury to persons living in homes containing this material because of the risk of acute and chronic illness from the gas released by the foam. The Canadian Government has prohibited the use of urea-formaldehyde foam insulation in residences and has made funds available for its removal. The cost of removal of urea-formaldehyde foam insulation from the walls of a residences in the United States has run from about $5,000 to $20,000.

It is estimated that there are about 500,000 homes in the United States that are insulated with urea-formaldehyde foam insulation. In the worst situation, some people have removed this insulation from their homes. Remedial measures including foam removal to eliminate or reduce problems associated with its presence have not been reviewed in the United States. Other countries such as Canada and Australia have addressed this problem.

<u>Technical Approach</u>: The review was based on existing information and building practices. It focused on technical issues concerning problem identification such as properties and composition of urea-formaldehyde foam insulation, the type of residential construction, and interactions between the foam and wall components. The review also focused on remedial measures to be taken to eliminate or reduce problems.

The information obtained in the study was also used as the basis for discussions concerning possible revisions of ASTM C951 "Standard Specification for Urea-Formaldehyde-Based, Foamed-in-Place Insulation." In this regard, an NBS research staff member chaired the ASTM C16.23 task group on urea-formaldehyde foam insulation (Spring 1984).

Products in FY84:

1. "Urea-Formaldehyde Foam Insulations: A Review of Their Properties and Performance" 9/84

5. Title: Wall Systems Air Leakage Research

Funding: $100K (DoE)

Objective: To develop test methods for evaluating the movement of air into and within large commercial buildings and to determine the efficiency of the ventilation systems of commercial buildings in providing a mechanism for removing contaminants at a minimum energy cost.

Problem Significance: In comparison to residential buildings, little data exists on the air leakage and air movement in large commercial structures. What data does exist indicates that modern office buildings are relatively tight and are operated with little outside air. Such buildings may not be providing a sufficient quantity of outside air to remove contaminants generated in the building. Even buildings which have a total air exchange rate sufficient to remove contaminants, may have zones which require little heating or cooling energy and therefore use small amounts of air.

Technical Approach: A test method was developed for measuring the efficiency of ventilation in modern commercial buildings. This method determined the minimum amount of air exchange which is effective in removing contaminants from the work space. The method was based on the injection of a tracer gas into various zones of the building and determination of the build-up and decay of the tracer gas in the work space and in the exhaust air. Initially the NBS automatic air infiltration system developed for application to large buildings was used. Tests were made in at least three different commercial buildings and the results were used to determine the effectiveness of the ventilation systems.

Products in FY84:

1. "Measurements of Ventilation Rates and Ventilation Effectiveness" 5/85
2. "Ventilation Efficiency in Mechanically Ventilated Offices" 8/85

6. Title: Pressed Wood Model Evaluations

Funding: $71.25K (CPSC)

Objective: The objective of this project is to evaluate the ability of an indoor air quality (IAQ) model developed by the National Academy of Sciences to predict the level of formaldehyde in controlled laboratory situations and field situations due to pressed wood products.

Problem Significance: Formaldehyde is a contaminant which is introduced into buildings by building products such as plywood, particle board and wood paneling. Models currently being used by CPSC to predict formaldehyde levels have not been adequately tested. There are simplifying assumptions made in developing these models which should be checked. An evaluation of these models is required to determine their ability to predict the formaldehyde levels in order to determine the nature of the errors introduced in the analysis being performed by CPSC.

Technical Approach: NBS will evaluate the indoor air quality model in the two computerized forms currently being used by CPSC: a one compartment model which treats the house as a single unit and determines the average formaldehyde concentration; and a two compartment model which divides the house into two compartments and determines the average formaldehyde concentrations in each compartment.

A series of controlled experiments in a chamber in the laboratory will be performed. The chamber was constructed in such a way that the temperature, humidity, air infiltration and the ventilation efficacy could be controlled. The chamber was calibrated to determine its absorption and emission characteristics of formaldehyde. Then a series of conditioned pressed wood products whose formaldehyde emission rate will be determined by the Formaldehyde Emission Surface Monitor (FESM) developed by Oak Ridge National Laboratory will be introduced in the chamber. The formaldehyde levels in the chamber will be measured and compared with the predictions made by the IAQ model.

Products in FY84:

1. NBSIR entitled "Evaluation of Indoor Air Quality Models for Predicting Formaldehyde Levels due to Pressed Wood Products." 2/85

Appendix B - FY85 Project Summaries

1. Title: Infiltration/Ventilation - Large Buildings

Funding: $115K (DoE)

Objective: To develop test methods for evaluating the movement of air into and within large commercial buildings and to determine the efficiency of the ventilation systems of commercial buildings in providing a mechanism for removing contaminants at a minimum energy cost.

Problem Significance: In comparison to residential buildings, little data exists on the air leakage and air movement in large commercial structures. What data does exist indicates that there is a wide range of air leakage rates in large buildings. Some large office buildings have been found to be so leaky that it is difficult to maintain comfortable interior conditions. At the other extreme, if a modern office building is relatively tight, there may be times at which it is operated with little outside air. Some buildings may not be providing a sufficient quantity of outside air to remove contaminants generated in the building, and in other cases buildings may be overventilated resulting in a waste of energy. Even buildings which have a total air exchange rate sufficient to remove contaminants may have zones which require little heating or cooling and therefore receive small amounts of air. Also, the design of air distribution systems and the placement of internal partitions may result in uneven distribution of what would otherwise be an adequate amount of ventilation air.

Technical Approach: Test methods already developed for measuring the efficiency of ventilation will be applied to modern commercial buildings. These methods will determine the amount of air exchange which is effective in removing contaminants from the work space. The methods are based on the injection of tracer gas into various zones of the building and determination of the build-up and decay of the tracer gas in the work space and in the exhaust air. Initially the NBS automatic air infiltration system developed for application to large buildings will be used. The procedure will be evaluated by testing at least three different commercial buildings and using the results to determine the effectiveness of the ventilation systems.

NBS will also work with Brookhaven National Laboratory in (at least) one of the commercial buildings being studied to compare automated tracer gas infiltration and ventilation measurements with those obtained using passive perfluorocarbon tracer samplers.

Products in FY85:

1. NBSIR, "Simultaneous Room/System Modeling and Water/ Pollutant Migration". 3/85
2. NBSIR, "Validation of TARP". 3/85
3. Technical paper for ASTM, "Air Infiltration and Ventilation in Large Office Buildings". 5/85

2. Title: Pressed Wood Model Evaluation (continuation of FY84 project)

Funding: $116.25K

Objective: Same as FY84.

Problem Significance: Same as FY84.

Technical Approach: Same as FY84.

Products in FY85:

1. NBSIR entitled "Validation of Models for Predicting Formaldehyde Concentrations in Residences due to Pressed Wood Products." 10/85

3. Title: Development of a Plan for a General Indoor Air Pollution Concentration Model

Funding: $50K (EPA)

Objective: The purpose of this proposal is to develop a framework for a comprehensive computer model to simulate dynamic pollutant movement and concentration variations in buildings.

Problem Significance: EPA needs a general and comprehensive model which can predict the extent, severity, and duration of indoor air pollution. Such a model, when developed, should be useful in the evaluation of various indoor air quality control systems as well as for policymaking processes.

Technical Approach: Most of the previous work reported for indoor air pollution modeling is based on a simplistic one-room dilution model which ignores the thermal effects and mixing dynamics.

A comprehensive analysis of pollution migration in buildings requires accurate simulation of all processes affecting pollutant concentration. These processes are infiltration, generation, dilution, reaction, removal, and exfiltration. NBS has recently developed a comprehensive dynamic building simulation model called TARP. In addition to detailed thermal conduction and radiation calculations, TARP computes infiltration and interroom airflows by considering the flows through all openings (doors, cracks, etc.) and requires a mass balance in each room. It can serve as a framework for adding the other components of the contaminant equation.

TARP will have to be expanded primarily in the following areas: (1) Detailed models will have to be developed for generation, reaction, and removal of various contaminants. (2) An air handling/ducting system model is needed to complete the simulation of forced interroom airflows and filtration devices. (3) The effects of interroom convection must be understood so that the simplified model can be developed. This area is primarily concerned with local air velocities, ventilation effectiveness, and removal of contaminants which have localized sources. Detailed models would be too time consuming to include in long-term simulation.

<u>Products in FY85</u>:

1.	NBSIR, "IAQ Modeling Workshop Report".	4/85
2.	Technical Paper, "Indoor Air Quality Status Report".	8/85
3.	NBSIR, "Indoor Air Quality Modeling, Phase I Report, Framework for Development of General Models".	10/85

Appendix C - Projects Expected to be Funded in FY86

1. Title: Infiltration/Ventilation - Large Buildings (this is a continuation of the FY85 project)

Funding: $120K (DoE)

Objective: Same as FY85.

Problem Significance: Same as FY85.

Technical Approach: The test methods developed in FY85 for measuring ventilation efficiency will be applied to five office buildings. Measurements of the distribution of contaminants in these office buildings will also be made. The contaminants which will be measured will be CO_2, CO, respirable particles in the range 0.3 to 0.5 μm, 0.5 to 0.7 μm, 0.7 to 1 μm, 1 to 5 μm, and 5 to 10 μm, formaldehyde and radon. These measurements will produce both a data set on contaminants in office buildings and also an assessment of the concept of ventilation efficiency in characterizing the ability of building ventilation systems to remove contaminants.

In conjunction with NIOSH, NBS will study the relationship between the level of contaminants and the operation and design of the ventilation system in the Columbia Plaza Building. In addition to the contaminants listed above, NIOSH will measure the levels of micro-organisms and allergens in the building. These data will be analyzed by NBS and NIOSH to determine the relationship between the performance of the ventilation system and the levels of indoor contaminants.

Products in FY86:

1. NBSIR on Ventilation Efficiency and Contaminant Levels in Five Office Buildings. 9/86

2. NBSIR on the Relationship of Ventilation System Performance and Indoor Levels of Contaminants in the Columbia Plaza Building. 12/86

2. Title: Evaluation of Barriers on the Emission of Formaldehyde from Pressed Wood Products (this project is a follow on of the FY85 formaldehyde emission project)

Funding: $75K (EPA)

Objective: To determine the effect of remedial actions on the emission rate of formaldehyde from pressed wood products.

Problem Significance: The emission of formaldehyde from pressed wood products has been studied only under ideal conditions. It has been shown that certain pressed wood products can emit large amounts of formaldehyde. It is possible however that simple treatments of the products can reduce the formaldehyde emission rate at little or no cost.

Technical Approach: NBS will use eight of its medium size chambers for measuring formaldehyde emission from pressed wood products to evaluate the effect of several simple treatments to the products on the emission rate of formaldehyde from the products. NBS will consider treatments which can be applied both in the manufacture of the pressed wood products and also as a retrofit measure. The effect of barriers and absorbers such as floor coverings and paints will be evaluated. In addition, NBS will evaluate the emission rate characteristics of several new products of both U.S. and European manufacture to determine their emission rate characteristics. Each product tested will be conditioned at 23°C, 50% R.H. for a period of two weeks. The product's normal HCHO emission rate will be measured at six different HCHO background levels from 100 ppb to the product's shutdown point. Two-thirds of the products will then be treated, one-third of the products will be left untreated. After a period of one week, the products will be retested to determine the initial effect of the treatment on the products. After one month, the treated products will be retested.

Products in FY86:

1. NBSIR on Effect of Barriers on HCHO Emission from Pressed Wood Products. 11/85

3. Title: Remedial Measured for Reducing Formaldehyde Emissions and Concentrations. (This project is also a follow on of the FY85 Formaldehyde Emission Project.)

Funding: $57K (CPSC)

Objective: The purpose of this study is to examine the methods available for reduction of both emission rates and concentrations of formaldehyde. These methods shall include, but not be limited to coatings, barriers, air cleaning, formaldehyde removal, air exchange and product/house treatment.

Problem Significance: While the prediction of the exposure level for an individual person is a very complicated problem, the use of the indoor air quality (IAQ) computer models has shown that under certain conditions of temperature, relative humidity, air exchange, loading, etc., relatively high concentrations of formaldehyde can exist. Tests performed by NBS for CPSC have shown that for bare pressed wood products there is a good agreement between IAQ models and measurements in a simulated house.

A person is not often exposed directly to the emission from a pressed wood product. For example, when particle board underlayment is used as a flooring material it is usually covered with tile or a carpet and padding. Another example could be a kitchen cabinet made with medium density fiberboard (MDF) where the MDF is usually finished with a coating or covered with another material.

Two important pieces of knowledge are lacking which CPSC needs in order to assess solutions to high formaldehyde concentration problems. The first is the effectiveness in reducing formaldehyde emission rates of coatings and other materials used to cover pressed wood. The second is the effectiveness of other actions which can be taken to reduce these concentrations to acceptable levels in those homes which exhibit a problem.

Technical Approach: This project will be divided into three tasks:

1.) Examine methods for formaldehyde concentration reduction;

2.) Experimentally test and validate those methods which appear most promising and for which insufficient testing has been conducted to allow reasoned evaluation of effectiveness; and

3.) Identify the most cost-effective, presently available methods for the various expected cases (for example sources, conditions, etc.) and identify where further research is needed.

Products in FY86:

1. Letter Report: Identification of Formaldehyde Reduction Methods. 2/86

2. Letter Report: Evaluation of Remedial Measures for Reducing Formaldehyde Emission - Test Results. 7/86

3. NBSIR: Effectiveness of Remedial Measures for Reducing Formaldehyde Emission for Pressed Wood Products. 9/86

4. Title: A General Indoor Air Pollution Concentration Model. (This is a continuation of the FY85 porject on IAQ modeling.)

Funding: $100K (DoE)
$100K (EPA)

Objective: The purpose of this proposal is to develop a comprehensive validated computer model to simulate dynamic pollutant movement and concentration variations in buildings.

Problem Significance: Same as FY85.

Technical Approach: The model framework resulting from the FY85 work will be used to develop a comprehensive indoor air pollution predictive model. It will cover one-compartment fully mixed (one-node) and multi-compartment fully mixed cases. It will also include the two-node cases for one- and multi-compartment cases. In addition, convection simulations will be covered for the two- and three-dimensional cases for a single compartment. Several pollutants will be covered.

Products in FY86:

1. NBSIR for the General Model for Predicting Indoor Air Pollution in Buildings. 9/86

5. Title: Micro-Modeling of Contaminant Concentration in a Space

Funding: $96K (NBS)

Objective: To develop models for predicting the distribution of contaminants within spaces in buildings.

Project Significance: Many pollutants are released into a space from point sources and the distribution of such pollutants within a space is not uniform. Cooking at a range, hobby activities, smoking, and business machines are examples of such pollutant sources. Some pollutants are also believed to affect health when relatively high concentrations are inhaled for only a short time. Therefore there is a need to be able to predict areas where high concentrations will exist. Most modeling to date assumes complete mixing in a space or employs a two-compartment assumption with uniformity within each compartment. There is a need for validated models for the short-term exposures to pollutants which can result from such activities as cooking, for example, to which a housewife could be exposed as she stands near a range or side-stream exposure of non-smokers from smokers in a room. Certain subpopulations, for example small children, also spend much of their time in areas not typical of the average conditions in the space - i.e., near the floor. Such micro-models can also be used to predict ventilation efficiency in office buildings which would aid in the design of more effective office ventilation systems.

Technical Approach: Some recent Japanese papers have considered the micro-modeling problem. This research has shown that it is feasible, using first principles, to predict the distribution of contaminants in a space. This information will be used as a basis for developing simplified micro-models which will be verified by experiments within one of CBT's environmental chambers. Typical environmental conditions and pollutant source distributions found both in residences and office buildings will be modeled using the techniques developed by the Japanese researchers. From the results of these models, two typical situations will be simulated in the two-room chamber used for formaldehyde model validation and the results compared with the prediction of the models.

This information will be needed as part of larger IAQ modeling effort being carried on for EPA and DoE, which involves room-to-room and indoor-outdoor predictions.

Products in FY86:

1. NBSIR on models for predicting the distribution of contaminants in spaces. 9/86

Appendix D - Unfunded Proposals Showing CBT Capabilities

1. Title: Effects of Building Materials on Indoor Air Quality

Funding Proposed: $200K

Objective: To provide pollutant emanation rates for various pollutants with practical sized samples.

Problem Significance: In order to help indoor air quality (IAQ) control options, data is needed on 1) the emission of contaminants from materials in the structure and furnishings of buildings, and 2) the abilities of these materials to absorb and re-emit contaminants. While valuable data can be obtained from small-scale experiments on individual materials, some confirmatory data will be needed from large specimens which may include materials systems in simulated indoor air environments.

Technical Approach: Samples of a range of common organic (plastic) materials used in buildings will be obtained and emissions from them will be determined in small-scale experiments using very sensitive techniques such as gas chromatography/mass spectrometry. Then, in conjuction with the project officer, a selection will be made of organic materials of particular importance for further study. An investigation of the rates and extents of absorption of vapors emitted from the selected organic materials by other building materials will be investigated to provide data for use in model development. The work will include characterization of the building materials in terms of specific surface area and porosity and adsorption isotherms for important vapors, so that variations in these characteristics can be taken into account in the models.

The work will be carried out in three phases. In Phase I, small-scale experiments on a broad range of materials to identify the main emissions from them will be carried out. In Phase II, more detailed investigations will be carried out to provide more quantitative data on emissions from a small number of selected organic materials, with the absorption of the vapors by other building materials being investigated. In Phase III, the larger chambers available at NBS will be used for simulating the emission and absorption of vapors by materials systems in buildings.

Products Expected: Reports on results in suitable form.

2. Title: Method for Measuring the Efficiency of Devices for Removing Gaseous Contaminants from Air Streams

Funding Proposed: $100K/year for two years

Objective: To develop methods for measuring the efficacy of filters to remove gaseous contaminants.

Problem Significance: Activated charcoal filters and filters using porous alumina to hold potassium permanganate are being used to remove or chemically change gaseous pollutants in buildings. These devices are incorporated into the heating, ventilating, and air conditioning systems, similar to filters used to remove particulates. Particulate filters for buildings can be evaluated using ASHRAE Standard 52-76, "Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter." Over the years, attempts have been made to evaluate gas removal devices for some specific applications: however, no general methods exist for testing and evaluating these devices. Such methods are needed so effective and economical control methods can be promoted fairly in the marketplace for improved indoor air quality.

Technical Approach: Methods will be developed to evaluate the effectiveness of devices for removing gaseous pollutants from air streams. These methods will employ a test duct system in which a sample filter/device is challenged with several gaseous pollutants introduced into the intake air. The gaseous pollutants will be selected according to their odors and possible adverse health effects, and presence in the indoor air. The methods will include techniques for safely introducing metered amounts of pollutants into the intake air of the test duct system and measurement techniques using spectroscopy for determining the concentration of the gaseous pollutants in the intake and outlet air of the test duct system. The gaseous pollutant removal efficiency of the device can then be calculated from the measured data.

The methods will also include ways to measure the capacity of such filters, since their performance is affected by contaminants loading. It will then be possible to combine the removal efficiency of a device with its contaminant load so as to provide information for comparison between filters and to estimate systems effectiveness and economic analysis of various alternatives.

During this work, close cooperation will be maintained with the ASHRAE technical committees on gaseous contaminants and removal equipment. It is expected that ASHRAE would use the results of the study as a basis for a consensus standard for evaluating devices used in ventilating systems for buildings.

Products Expected: Reports submitted to ASHRAE for voluntary standard development.

3. Title: Biochemical Formaldehyde Monitoring

Funding Proposed: $100K per year for two years

Objective: The purpose of this project is to develop an inexpensive, sensitive, reliable, easy-to-use, biochemical method specific for measuring formaldehyde.

Problem Significance: Formaldehyde is a nearly ubiquitous toxic gas that is carcinogenic in laboratory animals. There have been many reports of symptoms due to formaldehyde in mobile homes where formaldehyde emitting materials are used, and in homes insulated with urea-formaldehyde foam. Present measurement techniques for formaldehyde are either expensive, subject to interference by other aldehydes, or not sensitive enough to detect low airborne concentrations. Table 1 shows the sensitivity of several of these methods. Bubbling air through water or aqueous sodium bisulfite ($NaHSO_3$) for 1 hour is required to collect enough formaldehyde for detection by current analytical methods. Passive collections by solid supports require even longer times.

Table 1. Formaldehyde Monitoring Methods

Method	Sensitivity for Aqueous Formaldehyde	Sensitivity for Airborne Formaldehyde (based on 60-min sample)
Chromotropic acid	0.25 μg/ml	0.1 ppm
Pararosaniline	0.1 μg/ml	0.04 ppm
MBTH (for total aldehydes)	0.3 μg/ml	0.015 ppm

Technical Approach: We proposed a method using a bacterial light-emitting enzyme system that may be capable of measuring concentrations in the range of pg/ml, which is about 10^4 times as sensitive as the methods shown in Table 1. The method may also lend itself to continuous monitoring of formaldehyde.

The enzyme formaldehyde dehydrogenase, which is isolated from yeast, specifically oxidizes formaldehyde while at the same time reducing nicotinamide adenine dinucleotide (NAD^+) to NADH. A highly sensitive bacterial system is currently used to assay for NADH:

$$NADH + FMN + H^+ \xrightarrow{\text{oxidoreductase}} NAD^+ + FMNH_2$$

$$FMNH_2 + O_2 + \text{long-chain aldehydes} \xrightarrow{\text{luciferase}} FMN + H_2O + \text{long chain acid} + h\nu \text{ (490 nm)}$$

The system is extremely sensitive because of the ability of photometers to detect small numbers of photons of light. Each photon corresponds to a small number of molecules of NADH being oxidized. (Theoretically, each molecule oxidized results in one photon, but some photons are absorbed by the solution. The efficiency of photon transmittance is determined by adding a known quantity of NADH to the solution after it has stopped emitting photons.)

Bacterial luciferase is conveniently available, coated on the surface of glass rods. Each rod may be used repeatedly hundreds of times by simply dipping it into the solution to be tested and reading photon emittance in a photometer.

Products Expected: Reports on the method to sponsor.

4. Title: Standard Protocol for Field Measurement of Indoor Air Quality

Funding: $100K

Objective: The purpose of this research is to establish a standard protocol for measuring the indoor air quality which would allow a meaningful comparison of collected data on indoor air quality in buildings.

Problem Significance: Indoor air quality measurements are affected by many factors: weather, envelope tightness, building operation, building occupancy patterns, design of the ventilation system, for example.

To date there is no standard procedure for collecting indoor air quality information which would allow for 1) an assessment of the accuracy of the data, 2) an assessment of the interpretation of the data and 3) the meaningfulness of an extrapolation of the data to other situations and for risk analysis. At present most data sets on indoor air quality are incomplete, lacking measurements of all important environmental parameters, complete descriptions of the buildings tested, measurements of the building air leakage and ventilation rates, descriptions of the test methods used, calibration or accuracy assessment of the instruments used, the sampling methods used etc. The National Bureau of Standard has extensive experience in the field monitoring of the environmental and energy performance of buildings and has produced assessments of the field methods for assessing the energy performance of buildings and its mechanical systems. Such field measurement procedures should be extended to include the measurement of indoor air quality.

Technical Approach: The National Bureau of Standards will develop a series of standard protocols for the field measurement of indoor air quality on commercial and residential buildings. Protocols will be established for each of the major classes of contaminants found in residential and commercial buildings (radon, formaldehyde and other organic compounds, combustion products such as CO, CO_2, NO, NO_2, NO_x, and particulates, and asbestos). These protocols will contain 1) a procedure for characterizing the building, its mechanical system, its usage and operation and reporting of occupant complaints and problems, 2) environment parameter which should be measured, 3) specific building tests which should be performed such as a measurement of the air tightness of the building, its air infiltration rate, and ventilation rate, 4) procedures used for measuring the various contaminants, 5) recommended sampling methods, 6) statistical treatment of the data, 7) a description of the equipment used and its required calibration, and 8) an assessment of the accuracy of the data.

Products Expected: Reports on suggested protocols.

5. Title: Methods for Measuring Ventilation Effectiveness

Funding Proposed: $100K first year, $150K second year

Objective: Study the mixing of ventilation air in the heated and air-conditioned spaces by experimental measurement and to arrive at a recommended procedure for determining the ventilation efficiency in commercial and institutional buildings.

Problem Significance: Although the criteria for mechanical ventilation is well established in terms of required outdoor air per occupant or per unit of occupied space, all existing criteria assume perfect mixing between the supply air and room air. All the recommendations are based on the assumption that concentration levels of the contaminant in the return air from the air conditioned and/or heated space are equal to the space average concentrations. In other words, the current ventilation design is based on 100% ventilation efficiency. This assumption, although extremely simplistic, has seemed to be adequate for most of the conventional buildings, which are quite leaky and over-ventilated using constant air volume systems. The combination of variable volume air systems and energy conservation practices to reduce air infiltration, create entirely different conditions. Variable air volume air supply systems (VAV) are designed to regulate the total supply air flow rate to the space by the space thermostat. The reduction of the supply air flow, however, is restricted so that it still maintains minimum outside air flow corresponding to the ventilation requirement. During periods of low heating or cooling demand, the supply air flow rate is so drastically reduced that it may not reach all the occupied zones in office buildings. The supply and return air grills are usually in the ceiling and sometimes located side by side in many of the modern office buildings. When the room heating and cooling requirements are low, the reduced air results in such a low outlet velocity at the supply air diffuser that it's throw is not enough to reach the occupied zone.

It should be noted that it is also possible to have the opposite of the above occur: that the effective ventilation rate of the occupied zone can be greater than the average ventilation rate induced by the building air handling systems. This will occur when part of the ventilation return is located near localized contaminant sources.

There is little data on the actual ventilation efficiency of modern HVAC systems. Data which do exist have been obtained in small structures and in laboratory environments. In addition, several different definitions of ventilation efficiency have been proposed and studied. At present there is no accepted method for determining the effective ventilation rate of actual buildings.

Technical Approach: A method will be developed for measuring the parameters required for determining the ventilation effectiveness in a general office building in which the source of air is through the mechanical ventilation system, adjacent zones of the building and air leakage through the building envelope. It is proposed to use a multitracer gas technique for determining the various air flows in an occupied zone of an office building. The office environment which will be tested will be divided into two zones - one through which the ventilation enters and the other the occupied zone. The rest of the building will be considered as a single zone. A different tracer will be injected into each zone and the level of all the tracer concentrations will be measured in all zones. Such a measurement technique would permit the determination of 1) the total amount of outside air entering each zone, 2) the flow of air into and out of the occupied zone and the ventilation zone and 3) the amount of air exchange between the test zone and the rest of the building. Though such a method appears technically complicated, the recent development of capillary absorption tubes for perfluorocarbon tracers makes such a measurement scheme extremely practical, potentially simple and inexpensive, if the tubes prove to be practical. It is proposed to develop this measurement method for ventilation effectiveness, demonstrate its practical application to typical office buildings and develop a draft standard practice or protocol for its use.

Products Expected: Reports on results as appropriate.

6. Title: Determining the Effects of Efficient Furnaces, Boilers, and Water Heaters on Indoor Air Quality

Funding Proposed: $100K

Description: Retrofitting existing furnaces, boilers and water heaters to make them more energy-efficient, or replacing these appliances can save large amounts of energy. Many of these measures decrease the air infiltration rate because less makeup air is required to satisfy the reduced amount of fuel combustion made possible. Flue gas restrictors reduce the exit of combustion gases. Heat reclaimers lower the temperature of flue gases, creating the need for fans to exhaust combustion gases. The effect of these measures may be to impair indoor air quality. Concentration changes of such combustion gases as carbon monoxide and nitrogen oxides will be determined before and after energy-efficient changes are made to appliances.

7. Title: Feasibility of Monitoring Indoor Air for Pathogenic Bacteria and Viruses by Serological Methods

Funding Proposed: $100K (Phase I)

Description: In the first phase, particles will be collected by standard methods; for example, cyclones. Particles will be extracted and the extract screened with sera or with synthetic monoclonal antibodies specific against a battery of pathogenic organisms. This type of testing is inexpensive, rapid, and does not require viable organisms or complex growth regimes. The need to incubate organisms may have contributed in the past to the difficulty of screening for viruses and many bacteria. If the first phase is successful, methods may be refined to characterize pathogenic microorganisms by particle size.

8. Title: Pollution Removal in Spaces by Natural Means

Funding Proposed: $100K

Description: Pollutant absorption on inside surfaces of building materials and furnishings is an important mechanism impacting indoor air quality. Studies using a few important contaminants will be made to investigate removal methods and to develop models.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here*)

This report outlines a suggested five year research plan for the Center for Building Technology (CBT) in support of resolving the emerging indoor air quality problem. The problem is defined, and the past research is summarized. The important Federal responsibilities are identified. NBS contributions and capabilities are noted. Future research needs are covered, and these form the basis for the CBT research plan, in cooperation with other Federal agencies, state and local governments, and the private sector.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

chemical measurements; engineering; indoor air quality; models; physical measurements; research plan

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