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Environmental Assessment

In Support of Proposed Interim Energy Conservation Standards for New Commercial and Multifamily Highrise Residential Buildings

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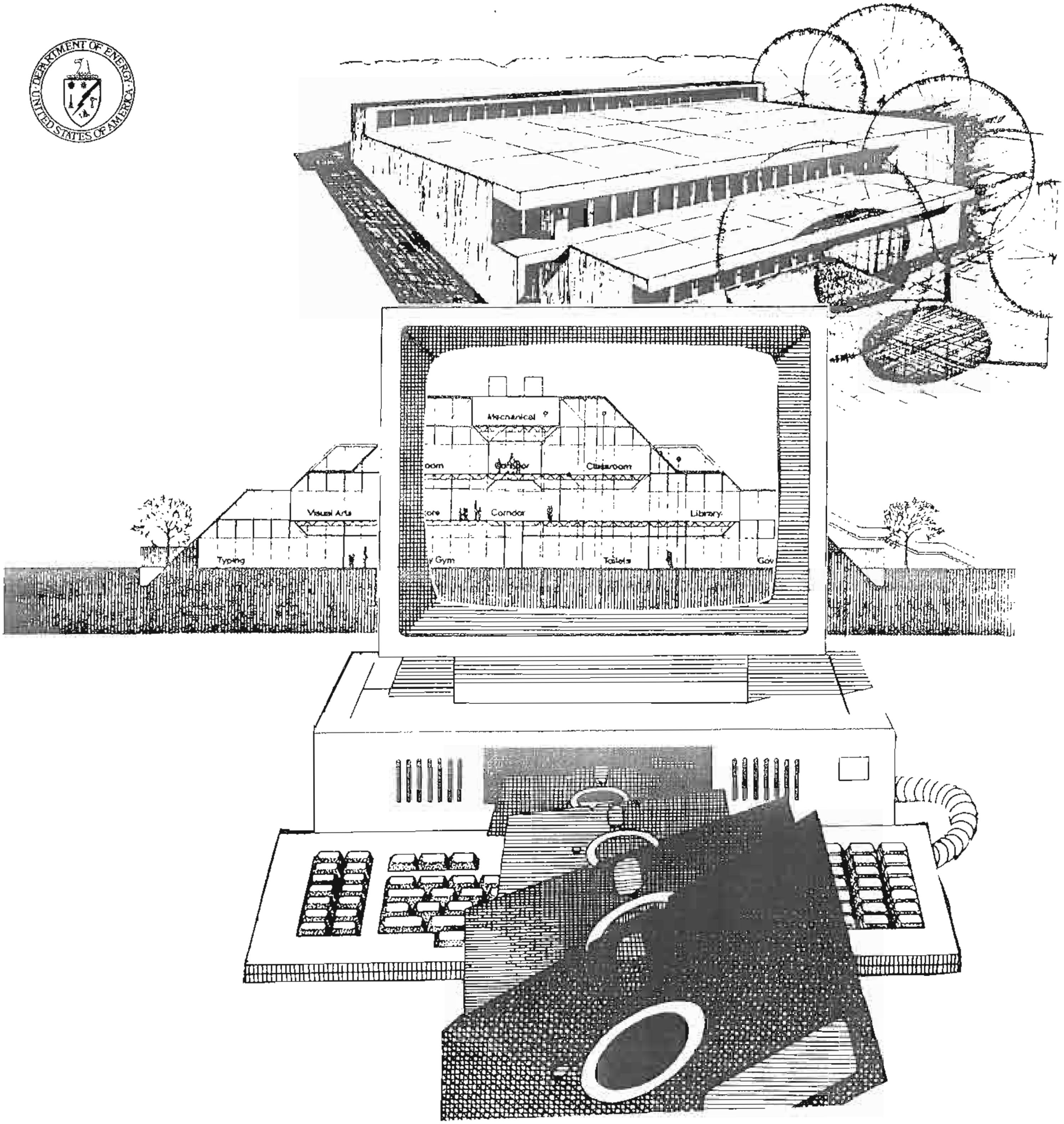

ACKNOWLEDGEMENTS

This assessment is the result of the efforts of several individuals and organizations. Funding for the project was provided by the Department of Energy's (DOE's) Buildings and Community Systems Division under the direction of John Millhone. Initially John Rivera and later Jean Boulin was the Program Manager at DOE, and Glen Wilfert was the Project Manager at Pacific Northwest Laboratory (PNL). Several staff members at PNL were involved in structuring the overall research effort and in writing assessment. Jenifer Callaway participated in all aspects of the assessment. James Droppo applied the basic algorithm for estimating changes in indoor pollutant concentrations. Graham Parker conducted the indoor air quality sampling undertaken to support the indoor air quality modeling effort.

Information in the assessment was reviewed by the following organizations: Bonneville Power Administration, Oak Ridge National Laboratory, Brookhaven National Laboratory, U.S. Environmental Protection Agency, and Princeton University.

FORWARD

This environmental assessment is a study done in support of the Standards and Guidelines Program, of the Architectural and Engineering Systems Group, Building Systems Division. The Energy Conservation Standards Act of 1976, as amended, requires the Department of Energy (DOE) to issue performance standards for the design of new buildings. These standards are to be mandatory for the design of new Federal buildings and voluntary for all other buildings. DOE is to publish interim standards, conduct a demonstration study of the impact of the interim standard, report to Congress on the results, and promulgate a final standard. The DOE has divided the development of these standards into two parts, residential buildings and commercial buildings. The residential building portion has been further divided into Federal and non-Federal buildings due to the specialized nature of Federal residential buildings, which primarily house military personnel, and the method used to procure housing.

This environmental assessment supports the Commercial Buildings Energy Conservation Standard portion of that program. It specifically supports the issuance of a Notice of Proposed Rulemaking (NOPR) for the Commercial Buildings Standard, which is a step in developing the Interim Commercial Buildings Standard intended to permit the broadest public comment and input to the standard under development. This NOPR will have a minimum of a 90 day comment period during which public hearings will be scheduled for Washington, DC, Chicago, IL, and San Francisco, CA. All comments will be carefully considered in developing the Interim Standard and in planning the subsequent demonstration study.

It is our belief that the standards being developed under the Architectural and Engineering Group Standards and Guidelines Program will provide important guidance in how to design new buildings to make substantially more efficient use of energy to create improved environments in which to live and work. These standards use the results of a considerable amount of research which has substantially advanced the state of the art of building science from where it stood a bare dozen years ago. Incorporation of these advances into our built environment can not only insulate us against future uncontrolled energy costs and availability fluctuations, but provide a more healthful and comfortable environment for us to live in, well into the 21st century.

Your comments on this assessment and the standards which it supports will be appreciated. Please send all comments to:

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DOE is greatful for the time and attention given to the Standards and Guidelines effort by many individuals and organizations throughout the United States. While considerable time and Federal dollars have been applied to this effort, this effort would not have been possible without the untold voluntary contributions of individuals and organizations from industry, academia, and government.

Jean J. Boulin, Group Leader
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SUMMARY

Title III of the Energy Conservation and Production Act (the Act) (Pub. L. 94-385), as amended, requires the Secretary of Energy to promulgate an energy performance standard that is designed to achieve the maximum practicable improvements in energy efficiency in new commercial buildings and to encourage the use of nondepletable energy sources.

Since the enactment of Pub. L. 94-385 in 1976, legislative enactments have changed the focus of the act. The Department of Energy (DOE) retains the responsibility for developing performance standards for all new federal, commercial buildings; this standard serves a dual purpose. For the federal sector, the standard sets mandatory performance levels for the design of federal buildings. For the private sector, the standard is voluntary and serves as a guideline, providing technical information and examples of energy-efficient design practices. The director of each federal agency will be responsible for enacting regulations or procedures to ensure that all new federal commercial building designs meet or exceed the proposed standard. Design professionals currently engaged in designing and constructing new nonfederal commercial buildings around the country are encouraged but not mandated to use it.

Pacific Northwest Laboratory (PNL) conducted this environmental assessment to address the possible incremental environmental effects of the proposed standard on selected types of commercial buildings (see Appendix A) constructed for the federal sector. This assessment was mandated by the National Environmental Policy Act of 1969, as amended (Pub. L. 91-190, January 1, 1970), and the implementing regulations of the Council on Environmental Quality (CEQ) (40 CFR Parts 1500-1508). This environmental assessment does not examine the environmental effects of the proposed standard on private sector commercial buildings, nor does it examine the impacts on federal or private sector residential buildings other than federal sector high-rise apartments. Under the proposed standard, several areas (economic, socioeconomic and institutional) have been analyzed in a separate document (Roop and King 1985) and are only summarized in this report.

Presently, the federal government's policy is to design federal commercial buildings to comply with the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 90A-1980. ASHRAE Standard 90A-1980 has been used as the baseline from which to measure the effects of the proposed standard. The proposed standard reflects an attempt to simplify compliance, to incorporate an improved understanding of building component interactions that affect energy use, and to ensure architectural and engineering flexibility in commercial building design. The proposed standard provides significant improvements in energy efficiency over ASHRAE Standard 90A-1980. For example, the simulated energy-use analyses of office-type buildings predicted that buildings designed according to the proposed standard would use 19% less energy than if ASHRAE Standard 90A-1980 were used. Case studies of the other 7 types of buildings showed an energy savings of 10% to 15%. A more detailed description of the differences between ASHRAE Standard 90A-1980 and the proposed standard is discussed in Chapter 2.0.

In analyzing the proposed standard, PNL separated commercial type buildings into ten categories on the basis of major functional and design differences. To evaluate the effects that the proposed standard would have on energy use, capital costs, operations and maintenance (O&M) costs, and the environment, plans for existing buildings from each of the ten categories of commercial buildings were obtained. A case-study building was selected for each category. Each test building was "redesigned" on paper to meet ASHRAE Standard 90A-1980 requirements in five different climates, then upgraded again to meet the proposed standard. Each of the ten buildings was tested in a series of computer simulations. The actual buildings used in the design study and the resulting energy- and cost-savings analyses are described in a series of reports entitled Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings, Volumes I through IV (see Appendix A) (PNL 1983). This assessment uses the simulated characteristics and performance of the ten case-study buildings to estimate the potential incremental environmental changes attributable to the proposed standard. The assessment is based on a subset of commercial building design possibilities under low, typical and worst-case conditions. The assessment brackets a wide range of potential effects in determining the incremental environmental consequences of the proposed standard.

This assessment of incremental environmental consequences emphasizes the possible alterations to building habitability (indoor air quality, health and safety) from the proposed standard. Alterations to building habitability were emphasized for two reasons. First, the impacts expected to occur in socioeconomic spheres or in the outdoor environment are very slight because of the proposed standard's similarity to ASHRAE Standard 90A-1980, its intrinsic design flexibility, and its emphasis on improved interrelationship of building components. Second, previous assessments of building standards for energy conservation have not incorporated extensive indoor environmental analyses, although this is an area of growing scientific concern.

The conclusion of this report is that the effect of the proposed design changes on building habitability, as well as on the outdoor environment, the economy and federal institutions, will be very small. Specific conclusions are summarized below.

HABITABILITY

In this assessment, habitability is expressed in terms of changes in various indoor air pollutant concentrations and concomitant occupant health and safety effects that can be related to design changes attributed to the proposed standard.

Indoor Air Quality

Various pollutants are released continuously or intermittently within commercial buildings. An indoor air quality computation model that uses specific pollution emission values (release rates) for selected materials was used to calculate pollutant concentration levels in the ten case-study buildings, based on an ASHRAE Standard 90A-1980 design for baseline conditions and on a proposed standard design. Incremental pollutant concentrations were calculated for radon, formaldehyde, particulate matter, CO and CO_2 and are shown in Table S.1.

TABLE S.1. Summary of Incremental Change in Indoor Air Quality from the Proposed Standard for Federal Commercial Buildings

Category	Radon (pCi/ℓ)		Formaldehyde (mg/m^3)		Particulate Matter W/HVAC Filter (μg/m^3)		Carbon Monoxide (mg/m^3)		Carbon Dioxide (μg/m^3)	
	Typical	Worst Case	Typical	Worst Case	Typical	Worst Case	Typical	Worst Case	Typical	Worst Case
Small Office	0	0	-0.021	-0.060	4	5	0	0	0	0
Medium Office	0	0	0	0	0	1	0	0	0	0
Large Office	0	0	0	0	6	10	0	0	0	0
Retail Store	0	0	0	0	1	1	0	0	0	0
Strip Store	0	0	0.003	0.008	5	8	0	0	0	0
Apartment	0	0	0	0	2	2	0	0	0	0
Hotel	0	0	0	0	6	10	0	0	0	0
Warehouse, Storage	0	0	-0.031	-0.088	0	0	0	0	0	0
Warehouse, Office	0	0	-0.008	-0.022	3	5	0	0	0	0
Assembly	0	0	-0.001	0.003	3	6	0	0	0	0
School Classrooms	0	0	0.002	0.007	2	2	0	0	0	0

Radon. Calculated values for indoor air concentrations of radon indicate that changes in building insulation materials; heating, ventilation and air conditioning (HVAC); lighting; and service water design do not increase the level of radon concentration for the commercial building designed to the proposed standard over the building designed to ASHRAE Standard 90A-1980.

Formaldehyde. The computed concentrations of formaldehyde depend on materials chosen for the buildings designed under the proposed standard. In the ten test buildings designed under the proposed standard, there was a tendency to replace insulating materials that emit formaldehyde with materials that emit other organic compounds (primarily because of cost and insulating performance criteria). In most of the test designs, therefore, levels of formaldehyde present in buildings designed to the proposed standard are predicted to stay the same or decline slightly in comparison to those constructed according to ASHRAE Standard 90A-1980. (Correspondingly, higher organic concentrations may occur temporarily immediately upon completion of construction in the buildings designed to the proposed standard.) Formaldehyde concentrations in new strip stores and new school classrooms may have slightly elevated formaldehyde concentrations. The increase in formaldehyde is very small. Concentrations of both formaldehyde and other organic compounds can be very age-dependent. The calculated concentrations are based on emission rates for new insulation materials. Aging will considerably reduce the actual long-term average concentration expected to occur in commercial buildings designed under either ASHRAE Standard 90A-1980 or the proposed standard.

Combustion Products. The estimated concentration of total suspended particulates (TSP) may increase slightly between the buildings designed under ASHRAE Standard 90A-1980 and the proposed standard because HVAC modifications in the latter tend to reduce the rate that air is passed through filters. (The volume of fresh air used to ventilate the building remains constant, however.) The incremental increase in TSP levels is small even under worst-case assumptions. However, in the test-design analysis, the total TSP for several building types (the retail store, the strip store, the hotel, and assembly building) are calculated under worst-case conditions to be over a value of 75 micrograms per meter cubed ($\mu g/m^3$) for both the ASHRAE Standard 90A-1980 design and the proposed standard design. No specific indoor air quality standard for TSP has been set, although the primary standard for outdoor air set by the National Ambient Air Quality Standard is 75 μ/m^3. The 75 μ/m^3 exceedence suggests that TSP sources such as tobacco smoking may need to be further controlled under worst-case conditions, and/or ventilation rates need to be increased to reduce TSP concentrations. CO and CO_2 concentrations were estimated to remain unchanged when substituting the proposed standard design for the ASHRAE Standard 90A-1980 design.

Effects on Health and Safety

In most of the test-building simulations, estimated pollutant concentrations did not change as a result of the proposed standard design. Where small increases in pollutant concentrations did occur, the health effect of these small changes is expected to be negligible. Although our current knowledge about health effects associated with common indoor air pollutants is limited, the small changes that appear possible with the use of the proposed standard design are unlikely to increase the risk of adverse health effects.

The proposed standard does not result in new or radical design approaches but rather in a fine-tuning of existing design approaches to reduce whole building energy consumption. Thus, the proposed standard is not in conflict with relevant health and safety standards. For example, the ASHRAE standard for ventilation (ASHRAE Standard 62-1981), which sets required amounts of outside air for acceptable indoor air quality, was applied to buildings designed under both the ASHRAE Standard 90A-1980 and the proposed standard. All other existing standards for building occupant's health and safety were also applied in both cases. Changes made to lighting, heating, ventilation, air conditioning, service hot water, and envelope design are expected to have very small incremental impacts on human health and safety.

EFFECTS ON OUTDOOR ENVIRONMENT

Improving the thermal resistance of a building's envelope will often require additional use of insulation and glass. More energy-efficient buildings will reduce the oil, natural gas, or electricity requirements for lighting, heating, and cooling. Any reduction in energy use will, in turn, decrease the volume of pollutants that are released into the environment because less energy will be developed and transported to heat/cool and light the building.

Any increase in the production of insulation and glass to improve the building envelope is assumed to have minimal environmental consequences. Ambient land, air, and water quality standards and the industry's ability to comply with those standards should not be substantially affected by the increased production because any additional emissions would be an extremely small part of current emissions to the environment. While it was not possible to calculate the net effect on the outdoor environment in this assessment, the effect most likely will be positive because reductions in pollutant emissions to the environment due to decreases in energy consumption will occur over the life of the building.

ECONOMIC EFFECTS

The total net benefit (reduction in cost of ownership and operation) of fully implementing the proposed standard for the federal sector is $165.6 million (1982 dollars). These energy expenditure savings represent about 3.6% of the expected cost of owning and operating the buildings constructed under the proposed standard during the 1981-2000 period. The reduction in energy expenditures alone is $141.9 million (a 17.9% reduction) and is composed of an electricity cost reduction of $140.6 million and a natural gas cost reduction of $1.3 million. O&M costs would decline by $20.3 million (2.0%) and capital expenses would decline by $3.4 million (0.1%). Capital costs would decline primarily from down-sizing heating and air conditioning equipment when the energy efficiency of the building is increased.

The indirect changes that occur as a result of imposing the standard on federal building construction would be modest. Total output for all industries would be reduced by about $140 million, almost the same magnitude of change as the net benefits. This decline in output occurs mainly in capital-intensive industries (primarily utilities) with some offsetting increase in output in more labor-intensive industries. Therefore, employment actually would increase by about 1,500 man-year of employment over the 20-year period, or an average of about 75 man-years of employment per year.

EFFECTS ON INSTITUTIONS

The proposed standard is not radically different from standards already being used by the federal government or recommended to private sector designers by ASHRAE. In developing the proposed standard, the DOE updated and improved ASHRAE Standard 90A-1980 to minimize the impacts of implementation on both federal agencies and private sector commercial building designers who might voluntarily use the proposed standard. Although not mandatory, use of ASHRAE Standard 90A-1980 is already an accepted and established practice within federal and private design communities. Therefore, federal agencies most likely will not experience any disruption to the procedures, calculations, and design practices that they already use when designing new commercial buildings.

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1.0 INTRODUCTION

The objective of this environmental assessment (EA) is to identify the potential environmental impacts that may result from implementing the proposed standard on federal sector construction of new commercial buildings. The EA does not examine the effects that the proposed standard may have as voluntary guidelines for the private sector, nor does it examine the environmental effects of proposed federal or private sector standards for residential construction. In this chapter, background information and statutory requirements that lead to the proposed standard and the EA are presented, followed by a discussion of the assessment's scope, objectives and approach. The report's contents are also briefly outlined.

1.1 BACKGROUND AND STATUTORY REQUIREMENTS

The Energy Conservation Standards for New Building Act of 1976 (the Act), as amended, 42 U.S.C. Sec. 6831 et seq., requires the Department of Energy (DOE) to issue voluntary performance standards for the design of new commercial and residential buildings. Federal agencies are required to comply with the commercial and residential building standards for the design of new federal buildings. For nonfederal buildings, compliance is voluntary, and the standards serve only as voluntary guidelines.

As originally enacted, Title III of the Energy Conservation and Production Act, Pub. L. 94-385, 90 Stat. 1144 et seq., requires the Department of Housing and Urban Development (HUD) to develop, promulgate, implement and enforce compliance of the performance standards. On August 4, 1977, the Act was amended by Section 304(a), 42 U.S.C. Sec. 7154, of the Department of Energy Organization Act, Pub. L. 95-91, which transferred from HUD to DOE the responsibility to develop and promulgate the standards. HUD retained its implementation responsibilities.

On November 28, 1979, DOE published proposed performance standards in the Federal Register, 44 FR 68120, et seq. The notice was controversial and generated over 1,800 comments. The comments included technical and other substantive criticisms of the proposed standards. Many commenters expressed concern that the proposed standards were not technically practicable or economically achievable. Furthermore, many commenters stated that the proposed standards placed too great a reliance upon the use of a complex computer program that they neither understood nor could afford to use.

Less than a year after the publication of the proposed standards, the Act was again amended, by Section 326 of the Housing and Community Development Act of 1980, Pub. L. 96-399 (October 8, 1980). This amendment required that DOE promulgate interim commercial and residential building standards by August 1, 1981, and extended the date for promulgation of a final rule to April 1, 1983. These interim standards were only to apply to new federal buildings. In addition, the Act required demonstration projects in at least two geographical areas.

In August 1981, Congress again amended the Act and also deferred the appropriation for the program from fiscal year 1981 to fiscal year 1982. Subtitle D of Title 10 of the Omnibus Reconciliation Act of 1981, Pub. L. 97-35 (August 13, 1981), amended the Act to create the term "voluntary performance standards;" eliminated the provision for a possible statutory sanction for noncompliance; added a provision that, except for federal buildings, "voluntary standards will be developed solely as guidelines to provide technical assistance for the design and construction of energy-efficient buildings;" and extended the deadlines for reporting requirements.

The legislative changes that have occurred since the Act was enacted in 1976 required a fundamental change in focus. DOE retains the responsibility for developing performance standards for all new buildings, but these standards now serve a dual purpose. The performance standards serve one purpose for the federal sector, where the standards set required performance levels for the design of federal buildings. The Act specifically directs that, except for federal buildings, voluntary performance standards "...shall be developed solely as guidelines for the purpose of providing technical assistance for the design and construction of energy-efficient buildings" (Section 304(a)(4)). Accordingly, the proposed commercial building standard serves a second purpose by providing sound technical information and examples of energy-efficient design practices for private sector guidelines.

As defined by the Act, the voluntary performance standard serves as an objective during the design stage. It does not apply to the operation, maintenance or energy consumption of a building once it is built. The voluntary performance standard operates by setting an energy consumption goal for a commercial building, i.e., a quantified target of energy consumption at the design stage and a method to calculate whether a design meets the energy consumption goal.

Subsequent to the analyses documented in this report, ASHRAE (The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.) substantially modified the form of the draft standard, strengthening its energy conservation requirements. ASHRAE issued its draft standard in July 1985 for a 90-day consensus review. ASHRAE is in the process of revising the draft standard for issuance as an ANSI/ASHRAE/IES Standard.(a) The DOE reviewed the ASHRAE draft standard and elected to incorporate the changes developed by ASHRAE into its standard for the design of new, federal commercial buildings.

The following information briefly describes the differences between the 1983 draft standard, which provided the primary basis for this assessment, and the current draft federal standard. The current version of the draft standard has been reorganized. Rather than addressing each component--envelope, lighting, HVAC--separately, the sections have been reorganized as follows:

1.0 Purpose
2.0 Scope
3.0 Definitions and Acronyms
4.0 Principles of Design, Implementation and Operation of Energy Conserving Buildings
5.0 Compliance
6.0 Mandatory Requirements and Practices for All Alternative Methods of Compliance
7.0 Prescriptive Requirements for Compliance
8.0 System Performance
9.0 Building Energy Criteria.

(a) ANSI - American National Standards Institute; IES - Illuminating Engineering Society.

In addition to reorganizing the draft standard, a number of other substantive changes were made. The 1983 draft standard had three separate envelope requirements: peak cooling, annual cooling, and annual heating. The current draft standard only contains a combined annual heating and cooling criterion. Application of an air transport factor criterion for HVAC systems has been eliminated in the current version. The minimum HVAC equipment efficiency levels are more stringent than those proposed in 1983. The lighting power levels are significantly reduced for many space types, while a few space types are allowed higher lighting power levels than in the 1983 draft standard.

The energy savings resulting from the current draft standard are expected to be similar to those for the 1983 draft. The new draft reduces energy consumption by 10% to 30% over ANSI/ASHRAE/IES Standard 90A-1980, depending on the building type and location, slightly greater than the savings for the 1983 draft. Also, the versions do not alter the analysis and findings of the environmental assessment. Building materials and envelope design remain virtually unchanged by the revisions. Accordingly, this revision of the standard will certainly not alter the findings of this assessment.

1.2 SCOPE AND OBJECTIVES OF THE ASSESSMENT

As discussed above, the proposed commercial building standard sets required performance levels to be applied during the design stage for federal buildings. The proposed standard encourages the fine tuning of existing design approaches and in most cases, it is not expected to result in radical commercial building design approaches. This assessment addresses the incremental environmental effects attributable to the application of the proposed performance standard. Those effects were determined by comparing "case-study" buildings designed and evaluated, through computer simulation, according to the current required practices and then to the proposed standard. Various quantified and unquantified environmental consequences attributed to increasing energy conservation in commercial buildings are discussed in this report. However, the emphasis of this analysis is directed toward the incremental changes in going from the ASHRAE 90A-1980 standard to the proposed standard, insofar as they can be identified.

This assessment is intended to fulfill several objectives. First, it addresses the potential for adverse environmental impacts resulting from implementing the proposed standard to the design of federal construction of commercial buildings. Second, it identifies certain limitations in our current understanding of the nature or extent of potential environmental impacts. Finally, the analysis is intended to provide an adequate basis from which DOE can determine whether implementation of the proposed standard is likely to result in a significant impact, or whether further research, in the form of an Environmental Impact Statement, should be conducted.

If promulgated by the DOE, the proposed standard will serve as an interim mandatory standard for federal sector construction and as voluntary guidelines for the private sector. The scope of this assessment is limited to the possible effects of implementing the proposed standard on the federal sector. The assessment does not examine effects that the proposed standards may have as voluntary guidelines for the private sector for the following reasons. First, the federal sector is finite and therefore easier to study than the disparate private sector. Second, the assessment focuses on individual building types and buildings rather than on the entire sector. Therefore, the conclusions of this assessment are also pertinent to the private sector. Third, accurately forecasting the implications of the standard on the private sector would be difficult and costly. It was determined that the minimal overall differences in results did not warrant the significant additional cost of conducting a broader study.

1.3 APPROACH USED IN THE ASSESSMENT

The approach used in this environmental assessment mirrors the testing procedure used to develop the proposed standard. Potential effects were examined through ten "test-designed" commercial buildings (one for each functional building category, e.g., small office). Each of the ten test-designed buildings was "modified" on paper by an architectural/engineer firm to meet the existing American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90A-1980 and then the proposed standard.(a) This process allowed real buildings to be used; detailed actual and simulated building characteristics also were used. The buildings designed to ASHRAE Standard 90A-1980 provided baseline characteristics from which the incremental effect of the proposed standard was measured. The data base and methodology are further explained in Chapter 3.

This approach is felt to provide a defensible analytical base. A building performance standard that epitomizes flexibility of design and construction therefore provides many options for satisfying the standard. To address the broad array of potential effects, each test building included design changes that would be required in five separate climate zones. The potential effects identified in this report are based on minimum, typical, and maximum values of indoor pollutant concentrations and thus bracket a full range of effects. Air quality/human health effects are based on the best health risk information available.

1.4 ORGANIZATION OF THE REPORT

The remainder of this assessment is organized as follows. Chapter 2 describes the proposed standard. Chapter 3 discusses in detail the general approach used in the assessment, followed by specific analyses of indoor air quality changes, human health and safety effects, outdoor environmental impacts, socioeconomic impacts (by reference), and institutional effects. Each of these specific analyses includes background information, the methodology used, and the results of the analyses.

Appendix A lists the titles of the multipart report that documents the development and testing of the proposed standard. They have been listed as a reference to those seeking a more comprehensive background or specific standard information. Appendix B contains detailed descriptions of the ten commercial

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(a) For example, when building features did not meet current ASHRAE Standard 90A-1980 and/or the proposed standard, those features were "altered" and analyzed by computer simulation. The redesigned structure was subjected to energy-use analyses using a complex computer program.

buildings used for the simulation tests. Appendix C describes the indoor air-quality monitoring experiment that was used to confirm the reasonableness of the computer model used to project indoor air-quality changes, while Appendix D provides a detailed description of the inputs, assumptions and limitations of that model. Appendix E documents the assumptions used to evaluate human health effects, and Appendix F lists persons and agencies contacted during the preparation of this report.

2.0 DESCRIPTIONS OF PROPOSED STANDARD AND THE BASELINE

This chapter provides summary descriptions of the proposed standard and ASHRAE Standard 90A-1980, which provides the baseline from which incremental effects are measured.

2.1 NO-ACTION ALTERNATIVE

The National Environmental Policy Act (NEPA) and its supporting Council on Environmental Quality (CEQ) guidelines stipulate that an environmental assessment include in its examination of alternatives the effects of a no-action alternative. However, this step has been eliminated in this assessment for the following reasons. First, the proposed interim standards for commercial buildings are mandated by law and preclude acceptance of a no-action alternative. Second, each federal construction agency has adopted an energy conservation standard as required by statute and the provisions of DOE's Federal Energy Management Program (FEMP).

2.2 ASHRAE STANDARD 90A-1980 BASELINE

ASHRAE Standard 90, "Energy Conservation in New Building Design," is internationally recognized and has been the basis of building energy codes, in whole or in part, in over 40 states in the United States. The standard was first developed in 1975 (ASHRAE Standard 90-75), and was updated in 1980 (ASHRAE Standard 90A-1980).

The current federal energy conservative policy is outlined in the Federal 10 Year Building Plan, published in 1983. In this plan, DOE has designated ASHRAE Standard 90A-1980 as the energy-efficiency standard for federal buildings, with the provision that the DOE life-cycle cost methodology be used to comply with the requirements of Section 545 of the National Energy Conservation Policy Act, Pub. L. 96-619. The federal government has not, however, adopted ASHRAE Standard 90A-1980 as its building efficiency standard.

ASHRAE Standard 90A-1980 is used as a surrogate for all of the federal construction standards that pertain to commercial buildings. It was chosen because it is included in the general requirements of the FEMP and because it provides a common ground for the various federal standards. This allowed DOE to consider only one commonly used standard, rather than the potential of several standards different in makeup but similar in requirements.

For the purpose of this analysis, ASHRAE Standard 90A-1980 represents baseline conditions. Therefore, the estimated effects of implementing the proposed action have been calculated as incremental changes, above and beyond any effects attributable to the use of ASHRAE Standard 90A-1980 as the design standard for new federal commercial buildings. The focus on incremental differences is particularly pronounced in the indoor air-quality analysis.

2.3 THE PROPOSED STANDARD

Consistent with the Congressional intent of providing voluntary guidelines to the private sector for construction of commercial buildings, the proposed standard is in the form of recommended revisions to the commercial buildings portion of ASHRAE Standard 90A-1980.

The proposed standard provides significant improvements in building energy efficiency over the ASHRAE Standard 90A-1980. The proposed standard is described in detail in Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings, Volume I and its Appendix A (PNL 1983). The most important features of the proposed standard are described below.

The proposed standard sets forth requirements for the design of new, federal commercial buildings. It is both a component performance standard and a whole-building performance standard.(a) The component performance portion covers illuminating systems (Section 4),(b) exterior envelope (the walls, windows, roof and foundation) (Section 5), selection of HVAC systems and equipment (Sections 6 and 7), service water heating (Section 8), and auxiliary systems

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(a) A performance standard specifies only a given level of performance, not the manner in which that performance is achieved. By contrast, a prescriptive standard (for example, an electrical wiring code) stipulates such things as materials, workmanship, etc.

(b) The section numbering shown here is according to the recommended format, which differs from the current ASHRAE Standard 90A-1980 numbering.

and equipment (Section 9). An alternative whole-building performance compliance procedure is included as Section 10. The proposed standard also allows the designer to exclude the amount of energy supplied by nondepletable energy sources from total energy chargeable to a proposed alternative design when the proposed alternative design uses solar, geothermal, wind or other nondepleting energy sources (Section 11). The standard <u>does not</u> specify requirements for operating or maintaining buildings. The components of the proposed standard are summarized in the following sections.

2.3.1 General Information

The proposed standard will apply only to the design of commercial buildings, although ASHRAE Standard 90A-1980 addresses both commercial and residential structures. (Note, however, that multifamily housing is considered to be a type of <u>commercial</u> building. The proposed standard specifically excludes manufactured homes and residential structures of three or less stories. Standards for such residential building constructed for the federal government will be issued separately.

The organization of ASHRAE Standard 90A-1980 is also changed in the proposed standard. For the first time this component-based standard will allow interaction between the requirements for different building systems; i.e., envelope compliance will now depend upon decisions made in the lighting compliance procedure. Hence, the sections of the proposed standard have been reordered to reflect this sequencing.

Further, the proposed standard reunites Sections 10 (Systems Analysis) and 11 (Requirements for Buildings Utilizing Solar, Geothermal, Wind, or Other Non-Depleting Energy Sources) with the component-based sections of the standard. These sections were part of the original ASHRAE Standard 90-1975, but they were later broken out separately from the main body of the standard for further study and refinement when the ASHRAE Standard 90A-1980 revisions were made. Section 12 of ASHRAE Standard 90-75 (Annual Fuel and Energy Resource Determination) has been eliminated.

The proposed numbering system is presented below, with the old section numbers following in parentheses.

1.0 Purpose (1.0)
2.0 Scope (2.0)
3.0 Definitions (3.0)
4.0 Illumination Systems (9.0)
5.0 Exterior Envelope Requirements (4.0)
6.0 HVAC Systems (5.0)
7.0 HVAC Equipment (6.0)
8.0 Service Water Heating (7.0)
9.0 Auxiliary Systems and Equipment (8.0)
10.0 Systems Analysis (90B-75R)
11.0 Requirements for Buildings Utilizing Solar, Geothermal, Wind or other Non-Depleting Energy Sources (90B-75R)

2.3.2 Changes in Envelope Design

The proposed standard for upgrading the exterior envelope requirements represents the most fundamental change of all the recommendations. ASHRAE Standard 90A-1980's separate treatment in the proposed standard of roof, floor, and walls is maintained. Roof and floor treatment in the proposed standard is similar to ASHRAE Standard 90A-1980 but is tightened; the thermal transmittance that is allowed decreases as heating degree days increase. Relaxed transmittances are allowed for roofs with skylights where daylighting benefit can be assured by using automatic daylighting controls.

Treatment of wall design in the proposed standard is completely different from ASHRAE Standard 90A-1980. Walls must now meet three separate criteria: peak cooling, annual cooling, and annual heating. Compliance with each criterion is demonstrated through an equation as a function of (1) conductive load, (2) solar load through windows, and (3) internal lighting load modified by daylighting, with each of these factors summed across building exposures. Climate, orientation, shading, building mass, operating schedule, and other important building-specific factors are included as coefficients in the equations. All relevant coefficients are provided in the standard as a function of building/climate-specific factors that are selected by the building designer. This approach works well for either worksheet or microcomputer compliance procedures.

The results from the lighting compliance section now enter into the wall compliance procedure as a power density.(a) Therefore, internal loads are considered in envelope design, allowing the designer to integrate design of the lighting and envelope systems. If the designer chooses a high lighting power budget under Section 4, then envelope compliance will be more difficult for the peak cooling and annual cooling criteria but easier for the heating criterion. However, the designer may also choose a daylighting approach to compliance (automatic controls required); then he/she is allowed significant credits for compliance with the peak and annual cooling criteria (and penalties for the heating criterion), and the envelope design will need to shift accordingly.

2.3.3 Changes in HVAC Design

In the proposed standard, HVAC systems and equipment and service hot water requirements are not radically changed from ASHRAE Standard 90-1980, but rather reflect the continuing incremental technical improvements that have occurred over the past decade. The equipment efficiency requirements mandated for January 1984 (by ASHRAE Standard 90A-1980) remain unchanged. New minimum efficiency levels are mandated for January 1988, and improve efficiency by about 2% to 8% over 1984 levels. Insulation requirements for pipes and boilers are also strengthened.

The proposed standard requires the designer to evaluate various system and control options during the design process, including the use of variable air volume systems (VAV), heat recovery, night setback, and reset control by exposure. In addition, it is proposed that the designer conduct an annual energy consumption analysis during the system selection process.

Finally, application of the Air Transport Factor (ATF) has been clarified, and separate ATFs have been recommended for ducted returns, nonducted returns, constant volume systems, and variable air volume systems.

(a) The building's energy use per square foot, usually expressed as Btu/ft^2.

2.3.4 Changes in Illumination Design

The proposed procedure for illumination system compliance (Section 4) is based upon ASHRAE Standard 90A-1980 lighting requirements, but saves a significant amount of energy and simplifies compliance. The major changes are listed below:

- Separate power budgets are required for the building interior, exterior activity areas, and facade lighting.
- In developing the power budget for the building interior, the designer no longer must calculate a budget on a room-by-room basis, but rather on an activity-by-activity basis. Therefore, for a large office building, only one calculation need be made for all of the office-type space, as opposed to the existing standard, where a separate calculation must be made for each individual office. The room configuration factor is still applied, but on an average basis rather than on a room-by-room basis. For the project test buildings, this simplified approach to budget determination reduced calculations by 70%.
- Small rooms (50 square feet or less) are exempted from the compliance requirements.
- Power densities are reduced by about 25% across all interior task activities.
- For all luminaires that are controlled by automatic daylighting sensors, 20% additional power is allowed and 10% is allowed for luminaires controlled by room occupancy sensors.
- Control requirements are more stringent to allow more economical use of illumination system.

2.3.5 Alternative Compliance by Systems Analysis

An alternative compliance procedure is included in the proposed standard for the following two cases:

1. if one or more of the components or systems of a proposed building design do not comply with the criteria of Sections 4 through 9 while one or more of the other components or systems exceed the stated requirements
2. if it is predetermined that an annual energy analysis will be used in lieu of applying the specific criteria of Sections 4 through 9.

For planned new, federal commercial buildings to be in compliance with the proposed standard using the alternative procedures, expected annual energy use of the building must be calculated and compared with the reference annual energy use for each fuel type for a building design to be in compliance with Sections 4 through 9 of the proposed standard. The calculation procedures used to determine the expected and reference annual energy use must be detailed enough to permit evaluation of the effects of the following data: climate, building, system design and operation, equipment, and internal heat generation. The calculations and analyses should be performed by a qualified person specified by a building regulatory agency or a registered engineer.

2.3.6 Use of Nondepleting Energy Sources

The amount of energy supplied by solar, geothermal, wind or other nondepletable energy sources through a specified collection, storage and distribution system is excluded from the total energy to be computed from the proposed alternative design. The design must be certified by a registered engineer.

2.3.7 Summary

The proposed standard is both a component performance standard and a whole-building performance standard. Whole-building performance compliance is determined by comparing a building's total expected energy use with a reference energy budget developed by analyzing the energy consumption of a building design in accordance with the component performance standard. The standard also provides incentives for using solar, geothermal, wind, and other nondepleting energy resources. The component performance (or prescriptive) approach is used because it is specific and familiar to the building design and construction professionals. The alternative whole-building performance procedure allows for greater flexibility in building design by allowing deviations from the specific component performance requirements as long as those requirements equal or reduce total energy use in the building as designed under Sections 4 through 9.

The proposed standard, when applied to federal-sector construction, would achieve the legislative purpose of redirecting federal policies and practices. The standard would also achieve the objective of improving efficiency of energy use and increasing the use of nondepletable sources of energy. When applied to private-sector construction as voluntary guidelines, the proposed standard would also encourage states and local governments to adopt such standards.

3.0 ANALYSIS OF POTENTIAL EFFECTS OF THE PROPOSED STANDARD

This chapter presents estimates of the potential effects of adopting the proposed standard for federal sector construction of new commercial buildings. Whenever possible, estimates of any differences between commercial buildings designed to ASHRAE Standard 90A-1980 and the proposed standard have been quantified. For some areas, such as health, safety and institutional effects, quantification was not possible, so comparisons are in qualitative terms.

3.1 FOCUS OF THE ASSESSMENT

Both the baseline (ASHRAE Standard 90A-1980) and one element of the proposed standard are component performance standards that are applied during the design stage of a commercial building's construction. The proposed standard incorporates changes that increase a building's energy efficiency both by modifying the individual component requirements and by strengthening the integration of those building components at the design stage. These design changes could have some effect on the building's habitability (indoor environment), the outdoor environment, the nation's economy, and affected federal agencies. Changes in the habitability of commercial buildings include potential effects on indoor air quality and the related human health effects on other health and safety-related features of the building (Section 3.3). The outdoor environment is affected by changes in the energy consumption of the buildings and by possible slight changes in the various process waste streams for certain industries (primarily insulation and glass manufacturing). These potential effects are discussed in Section 3.4. Economic and social effects stemming from adopting the proposed standard have been examined in a separate report (Economic Analysis, Proposed Interim Energy Conservation Standard for Design of New Federal Commercial Buildings) (Roop and King 1985), and are only summarized in this report (Section 3.5). Replacing the existing standard with the proposed standard may also lead to certain institutional impacts for affected federal agencies, as discussed in Section 3.6.

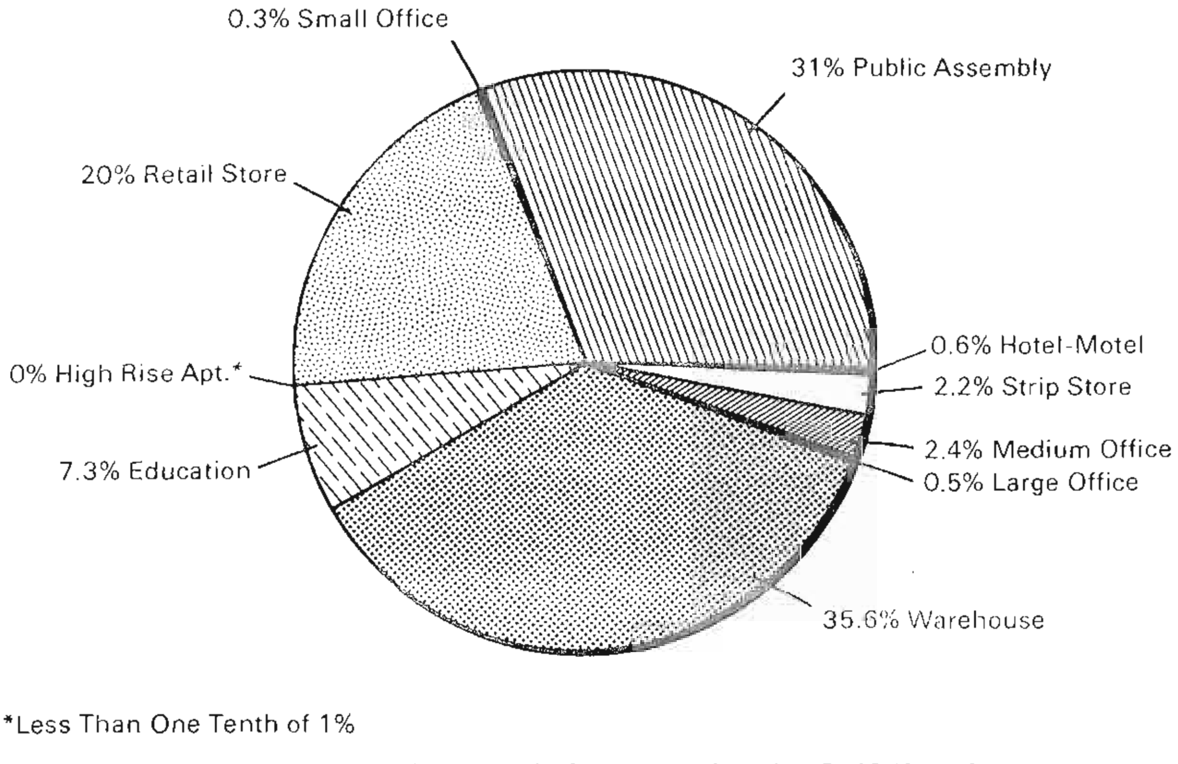
This report does not address potential changes in building comfort or aesthetic qualities because these are design choices that are not affected by the performance-standard nature of either alternative.

The proposed standard is a highly flexible approach to the energy-efficient design of commercial buildings. This inherent flexibility makes it difficult to pinpoint aggregate differences between the no-action alternative and the proposed standard. From the standpoint of potential environmental changes, actual material changes due to the proposed standard are primarily limited to the building envelope, where moderate changes in the amount of insulation and window treatments are possible for most categories of buildings in most climates. The potential changes to the outdoor environment and to indoor air quality were therefore examined primarily on the basis of minor envelope differences that would result from changing from the baseline to the proposed standard. Under the proposed standard, recommended changes in the HVAC systems often resulted in slightly reduced air flows in the test buildings, although the amount of outside air for ventilation (determined by ASHRAE Standard 62-1981) remained unaltered. Changes in this component of the proposed standard therefore also influenced the results of the indoor environment analysis. In general, lighting loads within each building are determined by specific task requirements. Although some general comments are made on lighting concerns, no specific comparison between ASHRAE Standard 90A-1980 and the proposed standard has been attempted in this report.

3.2 GENERAL METHODOLOGY

The proposed standard allows many building design possibilities. To best incorporate a range of such possibilities and, at the same time, establish a reasonable scope for the analysis, PNL based the analysis on ten test commercial buildings. Each building represents one of ten major categories of commercial buildings that are built in both the public and private sectors. In developing the proposed standard, the ten building types selected for testing included small, medium and large office buildings; two retail stores (one the major unit in a shopping mall, the other a typical strip store); a warehouse; a public assembly building; a high-rise hotel; a school; and a high-rise apartment building.

Most new federal commercial buildings can be classified into one of the ten categories, although specialty buildings (such as laboratories) comprise some portion of federal construction. However, specialty buildings are likely to be exempt from the proposed standard. Predictions of the amount and type of non-exempt federal construction were made in the economic analysis (Roop and King 1985). Figure 3.1 shows the distribution of the forecasted square footage (averaged over a 15-year period from 1985 to 2000) for the 10 categories. In some cases, federal commercial buildings in a given category are used for the same functions as private sector buildings in the same group (e.g., warehouses, office buildings). Other types of buildings, such as high-rise apartments, public assembly structures and retail stores that are built by the federal



*Less Than One Tenth of 1%

FIGURE 3.1. Forecasted Federal Construction by Building Category, 1985 to 2000 (average square feet)

government, may functionally resemble private sector buildings only in a general way. For example, federal government "apartments" are likely to be military housing units located at defense installations.

The actual buildings were chosen to represent the types of construction anticipated to occur in future years, but a specific design for a building (the school, for example) should <u>not</u> be interpreted as being strictly "typical" of buildings in that category. Attempting to characterize each type of building expected to be constructed in the future would be extraordinarily expensive. Because of time and funding considerations (as well as the anticipated low magnitude of impacts), a data base for the ten test buildings seemed most appropriate as the basis for the environmental analysis. The test buildings are described in more detail in Appendix B.

The data base for the test buildings was derived by "redesigning" the actual buildings by computer simulation, using a building energy-efficiency program for commercial buildings developed by DOE (called DOE2.1B). This simulation created the building parameters that were needed to meet both the proposed standard and the base-case alternative in five different locations. The locations were selected to include both the climatic and economic diversity of the continental U.S. The sites analyzed were Seattle, El Paso, Houston, Milwaukee and Washington, D.C. Each building was "reconfigured" with 2 to 4 "typical" HVAC systems, and then the resulting 27 test variations (2 to 4 x 10) were tested across 5 climates and 2 levels of energy-efficiency requirements (ASHRAE Standard 90A-1980 and the proposed standard), and against 3 different sets of economic conditions, for a total of 810 case studies. Additional analyses were conducted for daylighting(a) on 4 test buildings, and each building was tested for 2 levels of standards (ASHRAE Standard 90A-1980 and the proposed standard). Additional test runs were conducted to isolate the energy-use effects of the HVAC system section of the proposed standard. With this

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(a) "Daylighting" refers to introducing natural light to supplement or replace artificial lighting through strategically placed windows and skylights, thus reducing lighting energy consumption. Daylighting is encouraged, but not mandatory under the proposed standard. There are no provisions for daylighting in the component performance sections of ASHRAE Standard 90A-1980.

approach, plans for existing commercial buildings have been examined, and actual, not hypothetical, buildings have been analyzed.

The results of these comprehensive tests, which can be found in the reports referenced in Appendix A, were used to derive the materials and building configurations that were used in the following analyses. Table 3.1 lists the main parameters of all ten buildings for the Seattle location. With the exception of the insulation modifications noted in Section 3.3.2.2, the characteristics of the buildings designed for other locations are identical to the Seattle group. Greater detail about the equipment and material changes in the simulations can be found in the documents listed in Appendix A. However, it must be emphasized that the test buildings represent only a very small sample of what may be actually constructed under either the ASHRAE Standard 90A-1980 or the proposed standard. With both of the alternatives, performance standards, not prescriptive standards, were examined. Therefore, no specific materials or types of materials were required. The projected impacts presented in this chapter reflect the changes simulated for the test buildings only. Any attempts to project any specific conclusions of this analysis to future federal sector construction must be done very carefully, keeping in mind the wide latitude accorded the building architect and engineer in achieving compliance with the proposed standard.

3.3 HABITABILITY EFFECTS

The following sections examine the potential for changes in the habitability (indoor environment) of commercial buildings constructed according to ASHRAE Standard 90A-1980 and the proposed standard. The discussion focuses on the projected effect on indoor air quality (IAQ) and related impacts to the health of the building's occupants. The potential effects of various energy-conserving features (such as more efficient service hot water equipment) on occupant safety are discussed also, in a general way. However, use of these features is discretionary under either ASHRAE Standard 90A-1980 or the proposed standard, so no specific conclusions on their potential impact are made.

TABLE 3.1. Summary of Building Characteristics for Buildings in Seattle[a] (PNL 1983, Vol. IV)

Building Category	Number of Floors	Average Floor Height (ft)	Single Floor Area[b] (ft^2)	Total Carpet Floor Area (ft^2)	Number of Occupants	Standard ASHRAE 90A-1980 Design Air Recirculation (cfm)	Proposed Standard Design Air Recirculation (cfm)	Fresh Air Ventilation Rate[c] (ACH)
Small Office	1	16.0	2,500	1,488	19	2,547	2,230	0.570
Medium Office	3	12.0	16,500	34,155	330	47,130	46,390	0.667
Large Office	40	13.5	21,612	24,845	3,972	745,050	387,230	0.408
Retail Store	2	19.0	106,730	106,730	2,008	116,020	113,050	0.965
Strip Store	1	18.0	11,760	5,875	286	11,830	10,430	2.027
Apartment	9	8.8	46,308	166,710	1,310	301,000	272,000	1.Ca6
Hotel	10	9.6	31,550	152,490	2,900	183,000	154,840	1.522
Warehouse, Storage	1	24.0	38,640	0	20	243,080	243,080	0.237[d]
Warehouse, Offices	1	12.0	2,112	1,478	16	2,350	2,090	0.758
Assembly	1	18.8	14,150	9,198	614	12,463	11,810	2.922
School	2	13.0	42,230	35,473	2,161	43,660	34,630	0.770

(a) In locations other than Seattle, the air recirculation figures may vary slightly, causing the use of minor HVAC system modifications. The remaining building parameters do not change for the other locations.

(b) Average area of a single floor, total floor area can be derived by multiplying this number by the number of floors.

(c) ACH (air changes per hour) derived from ASHRAE Standard 62-1981 are the same for both the ASHRAE 90A-1980 design and proposed standard design.

(d) Assumed minimum ACH for structure.

3.3.1 Description of Approach

The IAQ analysis is based on a computer simulation of the generation, buildup and dissipation of various pollutants in occupied commercial buildings. In this section, the model used for this simulation is briefly described, and important assumptions that the model incorporates are noted. A monitoring experiment to spot-check IAQ in existing commercial buildings was conducted as part of this analysis. This experiment, its results, and its relationship to the IAQ model are also discussed. Finally, our current understanding of the relationship between IAQ and short- and long-term health impacts on building occupants is reviewed. Because of the complex nature of IAQ studies, the information in this section presents only the major aspects of the approach to the analysis. More detailed information may be found in the appendices. The monitoring experiment is described in Appendix C; Appendix D describes in detail the algorithms and equations used in the IAQ model, the pollutant source terms, and other variables used in the simulation; and Appendix E contains information on the relationships among certain pollutants and possible adverse health effects.

Studies of indoor air quality and related human health effects are a relatively recent development, and some aspects of both the behavior of known pollutants and human epidemiological responses are not clearly understood or documented. However, recent reviews (Yocum 1982; Walsh et al. 1984) indicate for many pollutants the lack of a strong link between outdoor ambient and indoor concentration levels; indoor pollutant levels often exceed outdoor levels. However, by considering both indoor and outdoor pollutant source relationships, the magnitude of monitored indoor values can be explained (Wadden and Scheff 1983). These relationships provide the basis for predicting incremental changes in indoor air quality. The approach used in the analysis of the proposed standard was designed to estimate the expected concentrations of major, recognized indoor air pollutants in most commercial buildings. Although any commercial building could have IAQ problems due to the presence of a wide variety of substances and/or activities (particularly if accompanied by an inadequate fresh air supply or unusual indoor pollutant release rates), this analysis focuses on changes based on the normal range of pollutant emissions and typical operations in commercial buildings. (See Table D.11 in Appendix D for a concise listing of the ranges used in the air-quality modeling.)

The predicted IAQ under ASHRAE Standard 90A-1980 and the proposed standard was derived by using a computer modeling approach that has been used and accepted by many IAQ experts (e.g., Miksch, Hollowell and Schmidt 1982; Molhave 1982). Estimates of pollutant concentrations based on building materials and usage parameters have been derived by this method and have corresponded reasonably well with monitored IAQ.

Potential changes in indoor air pollutant concentrations were estimated by computing concentration values for the ASHRAE 90A-1980 design and for the design changes resulting from the proposed standard. Concentrations were computed for selected pollutants (radon, organics and certain combustion products) that have suspected adverse effects on human health. Although other pollutants may be present inside buildings, concern about the quality of indoor air to date has been primarily focused on these substances. Numerous studies have been made of the release rates of these selected pollutants from various materials under varying circumstances. The emission rates used in the IAQ modeling effort were derived from these data sources (specific references are noted in the following section).

Long-term steady-state concentrations of average indoor pollutants were computed for each of the 10 buildings. For the building materials, contents, and usage, the computations were based on estimated emission rates designated by the design values for each test building. Average outdoor pollutant concentrations (from the air and underlying soils) were treated as a baseline to which internally generated pollutant emissions were added. Concentrations for each pollutant were computed for three release rates: minimum (min), middle (mid) and maximum (max) (see Appendix D), based on information in available literature. Min is defined as lowest expected emission rate; mid is a typical emission rate; and max is a worst-case emission rate. Together these numbers span the range of possible emission rates for pollutant sources expected to be found in the test commercial buildings.

The calculation of IAQ was based on the following assumptions:

- All fresh air supplies in the commercial buildings are set at the ventilation levels specified by ASHRAE Standard 62-1981 (see Appendix D). These values were identical for both the existing and proposed standards. In addition, all fresh air is assumed to be supplied by forced air supply equipment, and positive building pressurization is assumed to render the pollutant contribution of fresh air by natural infiltration (leakage) negligible. In reality, some natural infiltration occurs in most commercial buildings, so the modeled pollutant values may be marginally reduced by additional mixing with outside (fresh) air. Diluting the pollutant levels by infiltrating outside air will have the most effect when the HVAC system for the building is shut down (nights and weekends).
- Indoor particulate concentrations were computed both with no filtration and with 90% efficient filtration in the recirculated air. This feature accounts for the common practice of filtering the recirculating indoor air to control internally generated suspended particulate matter in commercial buildings.(a)
- Between the ASHRAE Standard 90A-1980 design and the proposed standard design, the changes in building materials that could affect indoor pollutant concentrations primarily involve the insulation materials.
- Air-to-air heat exchangers were not used in the model.
- The IAQ model calculates long-term average pollutant levels. Short-term variations occur around this average.

Pollutant release, buildup and dissipation rates used in the IAQ model for this analysis represent the best available information from recent scientific literature. However, much of the research conducted on IAQ has been conducted

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(a) The simulated effect of filtrating recirculated air was applied only to the particulate calculations. For pollutants such as organic compounds there are few commonly used pollution control practices other than removing or sealing the pollutant source materials, increasing the amount of outside air introduced to the building, and/or allowing the release rate to decay through aging.

on residential, not commercial buildings. (Commercial building IAQ is increasingly a focus of theoretic and applied research, however, and more data are gradually becoming available.) To justify the use of an emission rate derived from residential studies, the analysis included a short-term monitoring effort of a variety of existing commercial buildings. Indoor pollutant levels in five commercial buildings in the Pacific Northwest were monitored by PNL. Levels of radon, formaldehyde, particulate matter, and carbon monoxide were measured over a period of several days. Air exchange, temperature, relative humidity and wind speed were also measured. The level of indoor air pollutants measured in Pacific Northwest buildings demonstrated that the ranges of pollutant concentration levels projected by the IAQ model, based on emission rates from the literature, do occur in commercial buildings. Building and occupancy characteristics of the monitored structures were also used in conjunction with literature-derived emission rates to compare the pollution levels predicted by the IAQ model with the monitored values. The results produced by this exercise (see Appendices C and D) compared favorably with the actual values found during monitoring. A summary of the instrumentation, the sampling protocol, the building description, and the monitored data for each building is presented in Appendix C.

Each of the pollutants discussed in Section 3.3.2 has been associated with chronic and subchronic health effects in human epidemiological studies and laboratory experiments. However, with the exception of radon, quantifiable effects usually appear only at relatively high pollutant concentrations and/or exposure conditions that are much more severe than those encountered in most commercial building settings. The assumed relationship between low-level exposure to these pollutants and human health impacts that is described in the literature is usually derived through extrapolation rather than actual long-term observations. In addition, present understanding of the effect of accumulative low-level exposure and the possible synergistic (i.e., combined) effect of more than one pollutant is incomplete. For these reasons, most IAQ studies acknowledge various possible health effects but do not attempt to predict specific levels of impacts to building occupants.

3.3.2 Indoor Air Pollutants

Various pollutants are released within commercial buildings continuously or intermittently. These pollutants can originate from objects within a building (e.g., carpets or furniture), from building materials themselves (e.g., ceiling tiles, wall paint, particle board), or from the indoor activities of building occupants (e.g., smoking). Potentially hazardous pollutants with indoor sources include radon and radon decay products, formaldehyde and other organic compounds, airborne particles, and combustion gases [including CO, carbon dioxide (CO_2) and oxides of nitrogen (NO_x)].

Outdoor air pollutants enter buildings through mechanical ventilation systems or through infiltration. The indoor/outdoor air exchange rate can be decreased by tightening a building's envelope or by reducing outside air introduced by mechanical ventilation. Although these actions reduce the introduction of outdoor pollutants to the building, the contribution of outdoor pollutants to the long-term average concentration of nonreactive pollutants within the building is not affected. Outdoor pollutant concentrations represent a baseline (minus any reduction brought about by filtering) to which internally generated pollutant concentrations are added.

The following calculations do not account for the effects of any natural infiltration that may occur because positive building pressurization (while the building is occupied) was assumed to minimize this source of fresh air. The proposed standard also specifies maximum use of the HVAC economizer cycle (using increased outdoor ventilation during favorable outside weather conditions to minimize the need for mechanical cooling). While the economizer cycle is operating, internally generated pollutants will dissipate at a faster rate. However, because the operating time of the economizer cycle may vary greatly for each building type depending on the climate, the model did not account for this factor.

Presently, the federal government regulations that set standards for indoor air pollutant concentrations are limited to occupational exposure limits enforced by such agencies as the Occupational Health and Safety Administration

(OSHA). Outdoor limits for some pollutants have been set by EPA. The literature was also reviewed to determine commonly accepted indoor maximum concentration levels (or enforced limits from other countries) for specific pollutants. These values are presented as maximum concentration in Table 3.2, along with their sources. The standards, codes, and guidelines for radon, formaldehyde, airborne particles, CO, and CO_2 listed in Table 3.2 have been used to provide some perspective for the pollutant concentrations calculated in this assessment, but at this time are not enforceable and not universally accepted.

The specific indoor air pollutants evaluated in the assessment are radon, organic compounds (including formaldehyde), particulates, CO and CO_2. Each is discussed in the following sections. Included in that discussion is a brief review of the character of the pollutant, and the pollutant's health effects. The pollutant's indoor concentrations, predicted by the IAQ model for each of the ten test buildings, is also presented, and the indoor air quality effects based on the calculated values for indoor pollutant concentrations are summarized.

3.3.2.1 Radon Concentrations

Radon (^{222}Rn) is an inert, radioactive gas that occurs in the radioactive decay series of uranium (^{238}U). The magnitude of a radon source within a

TABLE 3.2. Recommended Maximum Indoor Air Pollutant Concentration Levels

Pollutant	Pollutant Value	Source
Radon	0.03 Working Level (WL) (6 picoCuries per liter @ 50% equilibrium)	U.S. Environmental Protection Agency (EPA)--Health and environmental protection standard for uranium mill tailings [40 CFR 192.12(b)(1)]
Formaldehyde	120 microgram per cubic meter(a)	ASHRAE Standard 62-1981.(b)
Airborne Particles	75 microgram per cubic meter(c) 260 microgram per cubic meter(d)	Primary standard (for protecting the public health) of the National Ambient Air Quality Standard for outdoor air (40 CFR 34.4-7). Enforced by the EPA.
Carbon Dioxide	4500 micrograms per cubic meter(a)	ASHRAE Standard 62-1981.(e)
Carbon Monoxide	5500 micrograms per cubic meter(a)	ASHRAE Standard 62-1981.

(a) Maximum long-term average exposure.
(b) Adopted from West German and Dutch guidelines.
(c) EPA annual average limit (outdoor air).
(d) EPA 24-hour limit (outdoor air).
(e) Adopted from a study of human metabolism requirements.

building depends both on the natural radioactivity of building materials and on the extent to which radon has infiltrated the building. Underlying soil and well water can be potentially major sources of radon; building materials and natural gas are usually only secondary sources.

Radon's flux rate (emanation rate) through soil varies from 0.1 to 10 picoCuries per square meter per second (pCi/m^2/s), depending largely on the mineral content of the soil in a specific locality. Mineralized areas may contain high-radon localities that are approximately ten times higher in radon than areas with different subsurface geological characteristics (Bruno 1981). Groundwater from these areas can also contain high levels of dissolved radon that is released to the atmosphere during use.

Unfortunately, no agency has mapped these high-radon localities. More precisely, there is no way to determine from geologic information whether an area or portion of a mineralized region has high radon releases. Attempts to correlate geological surface features with radon release rates have not been successful to date. Although some state health departments are aware of general areas that have naturally elevated radon releases, the data are insufficient to identify particular localities.

Because radon is a natural component of soil, it is present in earthen-based construction materials such as cement, concrete, and brick. The importance of including soil- and concrete-derived radon inputs in the model has been shown by Hernandez and Ring (1982). Concentrations of radon and its decay products (called radon daughters) have been measured in recent studies in commercial buildings. Abu-Jarad and Fremlin (1982) found high-rise buildings in England to have elevated radon concentrations in basement areas but lower radon concentrations on other floors. The indoor concentration of radon and radon daughters varied inversely with building ventilation rates. The flux rate of radon from the ground into a building depends on the composition and condition of a building's foundation. An intact concrete slab without cracks or leaks through pipes will reduce flux by a factor of about 10 (Bruno 1981); a vented crawl space can further reduce flux, but most commercial buildings do not have crawl spaces.

Because high levels of radon can occur in groundwater, another major potential source of indoor radon is by outgassing from water used within the building. The strength of this source depends on the amount of radon dissolved in the water supply, the extent to which well water is vented before entering the building, and the amount of water used. The amount of dissolved radon in groundwater is high (geometric mean of 130 pCi/ℓ for public water supplies and 920 pCi/ℓ for private water supplies) compared with surface water (geometric mean of 0.1 pCi/ℓ) (Kothari 1984). In areas known to have high soil content of radon in the U.S., residential potable groundwater supplies were found to have concentrations varying from 1,000 to 30,000 pCi/ℓ (Partridge, Horton and Sensintaffer 1979). Residential radon well water concentrations ranging from 330 to 52,000 pCi/ℓ were measured in Maine by Hess et al. (1982). In most parts of the country, commercial buildings rely primarily on water from municipal systems (i.e., water used for drinking and sanitation), rather than on directly supplied well water. Therefore, it is unrealistic to apply the high radon concentrations measured in some residential wells in an analysis of commercial buildings. The values used to calculate the contribution of water to indoor radon concentrations reflect this consideration.

The actual fraction of the total radon in the water that is outgassed within the occupied area was found to vary with usage; dishwasher, shower, and sink water had release fractions of 0.98 (max), 0.65 (mid), and 0.3 (min). An intermediate value of 0.6 is used for the fraction of total radon released in the current modeling. Appendix D, Table D.11, provides radon emission values used in computing indoor radon concentrations.

Health Effects. Radon gas and its decay products are present everywhere in concentrations that vary with location, the time of day, and weather conditions. Decay products in the air we breathe can become deposited and retained in the lungs, sometimes contributing to lung cancer. Studies show that uranium miners, who are subjected to elevated levels of radon and radon daughters, have higher rates of lung cancer than the general population (see Appendix E).

Because the effects of radon exposure seem to be cumulative, contributions from all sources (e.g., residences, commercial buildings, and outdoor air) must be considered. The severity of an individual's reaction to radon gas exposure will depend on many factors, such as the length of the exposure and the concentration levels. In the U.S., most lung cancer is caused by cigarette smoking, and about 4 out of every 100 Americans die of this disease (Evans et al. 1981). The risk of dying from lung cancer is therefore about 4% for the average American.

The research data developed from radon daughter epidemiology studies suggest that an absolute threshold exposure for lung cancer induction has not been identified. More detailed information on radon and its health effects is presented in Appendix E.

Expected Impact on Radon Concentrations. Radon concentrations were calculated for each of the ten test buildings. Concentration values for building designs representative of the ASHRAE Standard 90A-1980 and the proposed standard are presented in Table 3.3. The min, mid and max values relate to source-term assumptions discussed above. Background or ambient outdoor concentrations are assumed to be 0.25 pCi/ℓ.

None of the design changes in the proposed standard affect the estimated indoor radon concentrations in any of the buildings; the incremental changes of radon concentration in Table 3.3 are zero in all cases. Estimated concentrations vary from slightly exceeding the background to levels higher than the radon criterion value. The high radon concentration level predicted to occur in the warehouse results primarily from the low air exchange rate in that type of building, combined with emissions from the soil and the concrete walls and floor. Although the values in Table 3.3 represent specific sets of insulation materials, there is no reason to expect that any other choice of insulation materials would change the result (zero increment between radon concentrations for the ASHRAE Standard 90A-1980 design and the design under the proposed standard) because insulation materials are not generally radon sources. In the test buildings, a number of different materials were used that provided data for these projections, reflecting the variety of substances in actual use in commercial construction. The variations in radon concentrations in Table 3.3 derive, in part, from these differences (i.e., certain building materials emit more radon than others).

TABLE 3.3. Calculated Changes in Indoor Radon Concentrations (picoCuries/liter)

Building Category	ASHRAE Standard 90A-1980 Design			Proposed Standard Design			Increment		
	Min Value	Typical Value	Max Value	Min Value	Typical Value	Max Value	Min Delta	Typical Delta	Max Delta
Small Office	0.331	0.385	1.682	0.331	0.385	1.682	0.000	0.000	0.000
Medium Office	0.300	0.347	0.976	0.300	0.347	0.976	0.000	0.000	0.000
Large Office	0.294	0.329	0.474	0.294	0.329	0.474	0.000	0.000	0.000
Retail Store	0.279	0.305	0.649	0.279	0.305	0.649	0.000	0.000	0.000
Strip Store	0.262	0.275	0.599	0.262	0.275	0.599	0.000	0.000	0.000
Apartment	0.302	0.343	0.533	0.302	0.343	0.533	0.000	0.000	0.000
Hotel	0.283	0.313	0.435	0.283	0.313	0.435	0.000	0.000	0.000
Warehouse, Storage	0.484	0.714	4.583(a)	0.484	0.714	4.583(a)	0.000	0.000	0.000
Warehouse, Office	0.297	0.351	1.651	0.297	0.351	1.651	0.000	0.000	0.000
Assembly	0.261	0.270	0.485	0.261	0.270	0.485	0.000	0.000	0.000
School Classrooms	0.275	0.303	0.899	0.275	0.303	0.899	0.000	0.000	0.000

Note: 1. Radon Background = 0.25 picoCuries per liter.
2. Radon ASHRAE Standard 62-1981 = 3 picoCuries per liter.

(a) Concentration exceeded criterion value. Fresh air ventilation may have to be increased to reduce indoor concentration. Minimum outdoor air requirements are based on ASHRAE Standard 62-1981.

It is not the intent of this radon evaluation to dismiss the potential hazard of the presence of levels that exceed present criteria for safety. However, the comparison between the buildings constructed according to ASHRAE Standard 90A-1980 and the same buildings built according to the proposed standard clearly indicate that, whatever the materials, the changes in design criteria do not, in and of themselves, cause detrimental changes in radon concentration in commercial buildings.

Conclusions. Both the ASHRAE Standard 90A-1980 design and the proposed standard design were evaluated for radon concentrations with buildings meeting ASHRAE's ventilation standards for acceptable IAQ (ASHRAE Standard 62-1981). Calculated values for indoor air concentrations of radon indicate that changes in building insulation materials, HVAC, lighting and service hot water for the proposed standard design do not increase the level of radon concentration estimated over the ASHRAE Standard 90A-1980 design.

3.3.2.2 Organic Compounds (including formaldehyde)

Organic gases and vapors are known to emanate from many building materials and furnishings. Measurement programs have shown that a wide variety of organic contaminants occur in buildings. These solvent-related contaminants generally occur in low concentrations relative to industrial hygiene exposure levels, but in high concentrations relative to outdoor concentrations (Miksch, Hollowell and Schmidt 1982).

Organic pollutants are treated in this document as one complex class of indoor pollutants. These compounds tend to have common origins and have many of the same health effects. Moreover, because of the large number of compounds potentially present in a building, comprehensive discussion of each compound is impractical. Organic emissions are reviewed in this study as a large class of contaminants whose individual components may vary somewhat by building type and use. Table D.9 in Appendix D lists the major components of typical organic emissions in new office buildings. However, one of the compounds, formaldehyde, has been of special interest to the scientific and building construction community, and detailed data are therefore available. The discussion of potential specific effects of formaldehyde follow the more general review of organic pollutants.

Organic emissions from solvents in building materials were studied by Molhave (1982). Using 42 commonly used building materials in chamber emission studies, an average of 22 organic compounds were found in the air around the materials. A total of 52 different compounds were identified and summarized in terms of expected carcinogens, airway irritants and odorous compounds.

Rates of organic emissions from building materials decrease greatly as the building ages. Miksch, Hollowell and Schmidt (1982) estimate a nominal emission rate of 10 grams per hour (g/h) total organics for a hypothetical new office building having 10,000 square feet. This emission rate approaches zero for aged building materials. The major types of known organic contaminants emitted for new building materials listed in this study are aliphatic hydrocarbons, aromatic hydrocarbons, ketones, esters, and formaldehyde. Other types of organic pollutants may also be present. For aged building materials, only formaldehyde levels are listed as known.

Berglund, Johansson and Lindvall (1982) reported that in a new pre-school building in Sweden, most organic compounds decayed significantly within the first 6 months of occupancy. For example, 1-butanol decreased 4 to 14 times, toluene and pentanal thexanal 2 to 4 times. Concentrations of 22 organic materials studied after 6 months were far below their occupational threshold limit values. However, formaldehyde emissions remained at a level of about 110 $\mu g/m^3$.

Building occupants and their activities, and various operations also contribute to the emission of organic compounds. Sources of organic contaminants commonly occurring in commercial buildings include fire retardants in furnishings, paints and other finishing products, janitorial products, cigarette smoke, and motor vehicles and equipment exhaust. Measurements of emission rates have been made of some of these contributors. One wet-process photocopier using 1000 g of fluid per week has a nominal emission rate of 25 g/h. Cigarette smokers also contribute to indoor organics emissions. Miksch, Hollowell and Schmidt (1982) estimated that smokers in a hypothetical office building had nominal emission rates of 0.135 g/h formaldehyde, 0.068 g/h acrolein, 0.033 g/h nicotine, and 4 g/hr total particulates. Tobacco smoke is also a major source of benzo-[a]-pyrene (BaP), a carcinogenic hydrocarbon. In commercial buildings, concentrations of BaP measured during activities in public areas were about 10 to 22 nanograms per cubic meter (ng/m^3). Episodic emissions of organic compounds from building maintenance are estimated around 100 g/h and include aliphatic hydrocarbons, aromatic hydrocarbons, formaldehyde, amines, chlorinated hydrocarbons, and other organics (Miksch, Hollowell and Schmidt 1982). While occupant- and activity-related emissions of organic compounds can be an important part of a building's overall organic pollutant level, this analysis has not attempted to specify that contribution because it is not likely to change as a result of implementing the proposed standard.

Concern over organic pollutants from building materials in commercial buildings may lead to various mitigating actions. The main options include changing the building materials, increasing the fresh air supply temporarily, or allowing emission rates to decline before permitting a new building to be occupied.

Changing the building materials may not change the energy efficiency of the building, but it may change the cost of construction. Increasing minimum fresh air ventilation could change the energy efficiency of the building, depending on whether filtration or outdoor air is used to increase the fresh air supply or whether an air-to-air heat exchange system is installed. Effective control strategies that can be implemented without compromising building energy efficiency were discussed by Miksch, Hollowell and Schmidt (1982). A "drying out period" for new buildings to allow for aging reduction of emission rates and a direct source elimination for occupancy-related emissions were recommended as the most appropriate strategies. The option of an "aging" period, while not changing the construction costs or building's energy efficiency, may result in new costs due to the loss of income from delayed occupancy. To reduce this cost, some designers have suggested that one way to speed up the aging process is to increase both the temperature and air exchange rate in a new building for a period of time before occupation.

In this study, incremental changes in the concentrations of indoor organic pollutants were computed for the insulation materials specified in the redesign process. The emission rates used for the various insulation materials are given in Table 3.4. In cases where the insulation can be composed of several

TABLE 3.4. Organic Emissions From New Building Insulation Materials

Material	Description	Organic[a] Emission ($mg/m^2/h$)	Formaldehyde[b] Emission ($mg/m^2/h$)
Fiberglass	Fiberboard, 0.5"	0.017	--
Fiberglass	Batt, 3.0"	--	0.02 to 0.17
Mineral Wool	Insulation Batch	0.012	--
Organic	Woodfiber Board	0.120	--
Foam	Polystyrene	1.4	--
Foam	Polyurethane	0.12	--

(a) Taken from Molhave (1982).
(b) Comparable form of emission computed from 0.3 to 2.3 μg/g/day emission rate given by Gupta, Ulsamer and Preuss (1982). Organic emissions from fiberglass materials were based on fiberboard emissions.

different materials, the choice was made to use the most common material for which an emission rate was found. These rates were used to compute steady-state indoor organic concentrations based on a building's characteristics and planned operations. The approach of using a steady-state model to compute average, long-term indoor concentrations has been used by several authors (Molhave 1982; Miksch, Hollowell and Schmidt 1982; Hernandez and Ring 1982).

Changes in building materials will change both the amount and type of expected organic pollutants in the indoor air. In the ten test buildings redesigned to meet the proposed standard, the changes in the type and thickness of building insulation materials (see Table 3.5) represent a set of architectural/engineering choices based primarily on cost and engineering constraints. Therefore, the predicted differences in organic pollutant levels reflect this particular selection of types of insulation materials. If other materials are used, organic pollutant levels will also differ from those presented in Table 3.6. The computation allows the emission rate to vary with the thickness of the insulation material and the area of application. The change in concentration will be the sum of changes in wall and roof insulation materials.

TABLE 3.5. Changes in Insulation Thickness and Type of Material(a)

Building Category	City	ASHRAE Standard 90A-1980 Design		Proposed Standard Design	
		Roof	Walls	Roof	Walls
Small Office	Seattle	6.0" Batt	3.5" Batt	3.5" Batt	0.75" PolyS
	El Paso	3.5" Batt	3.5" Batt	1.5" PolyS	None
	Houston	3.5" Batt	1.0" PolyS	1.5" PolyS	0.5" MinB
	Milwaukee	3.5" Batt	1.0" PolyS	6.0" Batt	2.5" PolyS
	Washington, D.C.	3.5" Batt	3.5" Batt	2.0" PolyS	0.75" PolyS
Medium Office	Seattle	2.0" PolyS	4.0" Batt	3.75" PolyS	4.0" Batt
	El Paso	5.0" PolyU	6.0" Batt	2.75" PolyS	0.5" MinB
	Houston	3.0" PolyU	6.0" Batt	2.75" PolyS	1.0" PolyS
	Milwaukee	4.0" PolyU	6.0" Batt	4.0" PolyU	6.0" Batt
	Washington, D.C.	2.0" Pref	4.0" Batt	3.0" PolyS	4.0" Batt
Large Office	Seattle	3.0" PolyU	2.0" PolyS	2.0" PolyU	0.5" MinB
	El Paso	2.0" PolyS	2.0" PolyS	2.0" PolyS	3.0" PolyU
	Houston	2.0" PolyS	None	2.0" PolyS	0.5" MinB
	Milwaukee	3.0" PolyS	0.5" OrgF	3.5" PolyU	3.75" PolyU
	Washington, D.C.	3.0" PolyS	0.75" PolyS	2.75" PolyS	0.5" MinB
Retail / Store	Seattle	1.5" OrgF	None	2.5" PolyS	0.75" PolyS
	El Paso	1.0" MinB	None	1.25" PolyS	None
	Houston	1.0" MinB	None	1.25" PolyS	None
	Milwaukee	1.0" PolyU	Perlite	3.0" PolyU	2.5" PolyS
	Washington, D.C.	1.0" MinB	0.5" OrgF	2.0" PolyS	0.75" MinB
Strip Store	Seattle	2.25" Batt	2.25" Batt	3.5" Batt	6.0" Batt
	El Paso	1.5" PolyS	0.75" PolyS	2.25" Batt	0.75" PolyS
	Houston	1.75" PolyS	0.75" PolyS	2.25" Batt	None
	Milwaukee	6.0" Batt	6.0" Batt	6.0" Batt	3.5" Batt
	Washington, D.C.	2.5" Batt	1.25" PolyS	3.5" Batt	6.0" Batt
Apartment	Seattle	2.0" MinB	1.0" PolyS	2.0" PolyU	2.5" PolyS
	El Paso	3.0" MinB	None	2.5" PolyS	2.25" Batt
	Houston	2.0" MinB	None	3.0" Pref	None
	Milwaukee	3.0" PolyU	3.5" Batt	3.5" PolyU	2.0" PolyS
	Washington, D.C.	2.0" MinB	0.75" PolyS	3.0" PolyS	2.25" PolyS
Hotel	Seattle	2.0" Pref	1.0" PolyS	3.0" PolyS	1.25" PolyS
	El Paso	2.0" Pref	None	2.0" PolyS	1.0" PolyS
	Houston	2.0" Pref	None	2.0" PolyS	None
	Milwaukee	2.0" Pref	0.75" MinB	3.5" PolyS	3.5" Batt
	Washington, D.C.	2.0" Pref	0.75" PolyS	2.5" PolyS	1.25" PolyS
Warehouse Offices	Seattle	6.0" Batt	3.5" Batt	3.5" Batt	3.5" Batt
	El Paso	6.0" Batt	3.5" Batt	1.5" PolyS	0.5" MinB
	Houston	6.0" Batt	3.5" Batt	2.5" Batt	3.5" Batt
	Milwaukee	6.0" Batt	3.5" Batt	6.0" Batt	3.5" Batt
	Washington, D.C.	3.5" Batt	3.5" Batt	2.5" Batt	3.5" Batt
Warehouse Storage	Seattle	3.5" Batt	1.0" PolyS	3.0" PolyS	1.5" PolyS(c)
	El Paso	6.0" Batt	1.0" PolyS(b)	2.0" PolyS	1.5" PolyS(c)
	Houston	6.0" Batt	1.0" PolyS(b)	2.25" PolyS	0.5" MinB(c)
	Milwaukee	6.0" Batt	2.0" PolyS(b)	4.0" PolyS	4.0" PolyS(c)
	Washington, D.C.	3.5" Batt	1.0" PolyS	3.5" Batt	1.5" PolyS
Assembly (Church)	Seattle	3.5" Batt	3.5" Batt	3.5" Batt	0.75" PolyS
	El Paso	2.5" Batt	2.5" Batt	1.5" PolyS	6.0" Batt
	Houston	2.5" Batt	2.5" Batt	1.5" PolyS	0.5" MinB
	Milwaukee	3.5" Batt	3.5" Batt	6.0" Batt	6.0" Batt
	Washington, D.C.	3.5" Batt	2.5" Batt	2.5" Batt	0.75" PolyS
School	Seattle	3.5" Batt	2.5" Batt	3.5" Batt	6.0" Batt
	El Paso	2.5" Batt	1.0" PolyS	2.0" PolyS	1.5" PolyS
	Houston	2.5" Batt	1.0" PolyS	2.5" Batt	1.0" PolyS
	Milwaukee	6.0" Batt	3.5" Batt	6.0" Batt	3.5" Batt
	Washington, D.C.	2.5" Batt	2.5" Batt	2.5" Batt	2.5" Batt

(a) Material abbreviations are Batt = fiberglass, PolyS = polystyrene, PolyU = polyurethane, MinB = mineral board, OrgF = organic fiberboard, Pref = Preformed roof insulation, Perlite = loose material used to fill holes in concrete blocks.

(b) Area coverage reduced (start 14' off floor rather than 8').

(c) Area coverage expanded to entire exterior wall.

TABLE 3.6. Projected Total Organic Concentration[a] Increments in Buildings with Unaged Building Materials (mg/m^3)

City	Building Category	ASHRAE Standard 90A-1980 Design	Proposed Standard Design	Increment
Seattle	Small Office	0.082	0.594	0.511
	Medium Office	0.240	0.432	0.191
	Large Office	1.005	0.006	-0.999
	Retail Store	0.013	0.199	0.185
	Strip Store	0.002	0.003	0.002
	Apartment	0.315	0.792	0.478
	Hotel	0.031	0.043	0.013
	Warehouse	1.217	16.194	14.976
	Assembly	0.001	0.010	0.009
	School	0.020	0.024	0.004
El Paso	Small Office	0.062	0.942	0.880
	Medium Office	0.053	0.321	0.268
	Large Office	1.047	0.143	-0.904
	Retail Store	0.001	0.082	0.081
	Strip Store	0.065	0.021	-0.044
	Apartment	0.004	0.242	0.239
	Hotel	0.001	0.040	0.039
	Warehouse	1.375	11.294	9.919
	Assembly	0.001	0.026	0.025
	School	0.096	0.917	0.821
Houston	Small Office	0.782	0.947	0.165
	Medium Office	0.039	0.530	0.491
	Large Office	0.046	0.049	0.003
	Retail Store	0.001	0.082	0.081
	Strip Store	0.073	0.001	-0.072
	Apartment	0.002	0.030	0.028
	Hotel	0.001	0.010	0.009
	Warehouse	1.375	11.030	9.655
	Assembly	0.001	0.026	0.025
	School	0.096	0.096	0.000
Milwaukee	Small Office	0.782	0.073	-0.710
	Medium Office	0.046	0.046	0.000
	Large Office	0.103	0.126	0.023
	Retail Store	0.004	0.127	0.123
	Strip Store	0.004	0.004	-0.001
	Apartment	0.032	0.645	0.613
	Hotel	0.001	0.017	0.016
	Warehouse	2.372	23.585	21.214
	Assembly	0.001	0.002	0.001
	School	0.034	0.034	0.000
Washington, D.C.	Small Office	0.062	1.822	1.760
	Medium Office	0.036	0.355	0.320
	Large Office	0.444	0.066	-0.378
	Retail Store	0.004	0.132	0.128
	Strip Store	0.035	0.003	-0.032
	Apartment	0.237	0.982	0.746
	Hotel	0.023	0.050	0.026
	Warehouse	1.217	1.716	0.498
	Assembly	0.001	0.010	0.009
	School	0.015	1.198	1.182

(a) Including formaldehyde.

Both increases and decreases in organic emissions are expected as a result of the building envelope modifications.

Health Effects. The health effects of organic pollutants are relatively uncertain. Molhave (1982) summarizes the number of expected carcinogens, airway irritants, and odorous organic compounds that he was able to detect. However, the minimum exposure levels for the onset of health effects, as well as the requisite period of exposure, have not been clearly demonstrated (See Appendix E).

Expected Impact on Organic Concentrations. Table 3.6 contains the computed values for total organics emissions in all wall and ceiling insulation for each building type for each of the five cities (representing the expected effects of different climate zones on building insulation requirements). This table indicates that the insulation materials selected in the redesign process resulted in a tendency for organic concentrations to increase in the buildings designed according to the proposed standard. While the resulting level of insulation achieved by the materials specified in this report is fixed by the proposed standard, the choice of insulation material is not. Use of other materials to achieve the same thermal transmissivity of the envelope could change organic emissions. One or two structures in each city show decreases in organic emissions, and the remainder show increases. The values in Table 3.6 are based on new material emission rates from Table 3.4, and therefore reflect the expected concentrations that could be found when the buildings are new. The actual long-term, average concentrations expected in the buildings could be considerably lower because emission rates decrease as the building ages.

Although the emission rates of organic pollutants (Table 3.4) could conceivably produce concentrations high enough to cause some health concerns, long-term exposure levels for building occupants should be very low after an initial aging period (Miksch, Hollowell and Schmidt 1982). Most of these substances have a very rapid decay rate, with the exception of formaldehyde. Formaldehyde can be emitted at a fairly high (but constantly decreasing) rate for a longer period [its half life is considered to be about 58 months (National Research Council 1981b)]. Therefore, no long-term health effects are expected after an initial aging period, although a small percentage of the population may experience temporary discomfort related to the presence of formaldehyde and other organics in new buildings when they are initially occupied. The mitigation actions discussed earlier would have the same effect on buildings designed according to either ASHRAE Standard 90A-1980 or the proposed standard. However, mitigation through increased ventilation and filtration may not be as effective in some of the proposed standard buildings if the recommended reduced rates of air flow of return air are used. (See the discussion of this feature in the section on particulate matter.)

Formaldehyde. As mentioned above, formaldehyde is an organic compound of special interest and study because it is used in the manufacture of many building materials. Particle board, plywood, wall board, and similar construction materials are all major indoor sources of gaseous formaldehyde. Formaldehyde can also be emitted during combustion processes. However, formaldehyde produced by combustion has typically been of greater concern in the residential environment than in commercial buildings, where strong formaldehyde sources such as furnaces and stoves are required to be ventilated at code-defined rates. Formaldehyde is, however, a component of sidestream cigarette smoke (i.e., smoke released from the burning tip of a cigarette). Typically, about 1 milligram (mg) of formaldehyde is released for each cigarette smoked [National Research Council (NRC) 1981a].

Release rates for formaldehyde vary because many factors are involved. Anderson (1979) found that indoor formaldehyde concentrations in Danish homes are a function of air temperature, humidity, the air change rate, the ratio of particle board surface area to room volume, and the surface coating and type of particle board used. Age has also been identified as a factor in formaldehyde release; about half of the formaldehyde in particle board, for instance, is released over a period of 58 months (NRC 1981b). Ventilation rates and the amount of resinous material in a building seem to be the most important factors that contribute to formaldehyde accumulation.

Formaldehyde concentration data are available only for certain types of commercial buildings, such as clothing and carpet stores, dry cleaning establishments and funeral homes, where high concentrations are expected to occur. The formaldehyde concentrations in these facilities often exceed the value of

120 µg/m^3 (ASHRAE Standard 62-1981). For example, a survey of occupational environments showed maximums of about 3900 µg/m^3 in clothing stores and 6200 µg/m^3 in funeral homes (NRC 1981b).

In commercial buildings, formaldehyde emissions that are related to the building materials are hard to define because only limited factual data from studies are available for most types of buildings. One energy conservation study that did supply some data found that total concentrations of all aldehydes (including formaldehyde) inside an elementary school did not exceed 25 µg/m^3, which is very low (Yocum 1982). Wall and floor coverings in most commercial buildings are relatively well sealed with paint and other finishes for sanitary purposes. These finishing materials tend not to be formaldehyde-emitting materials and will, in fact, inhibit emissions from any underlying formaldehyde-emitting materials such as particle board.

Indoor formaldehyde concentrations are computed (see Table 3.7) as the sum of estimated emissions from smoking, building materials, and building furnishings. Smoking source terms (emission rate and concentration) are based on building occupancy (see Combustion Products discussion below). The building materials and furnishings source term is based on extrapolations from residential buildings for which data on various construction materials are available. The range of observed formaldehyde concentrations in nonmanufactured residences is used to define an indigenous formaldehyde emission rate, which is normalized by floor area.

This computation approach does not account for the extremes likely to occur in buildings used for the sale or storage of significant quantities of high formaldehyde source materials (e.g., plywood, particle board, furniture, clothing, and rugs). These types of buildings are expected to have considerably higher concentrations than found in other commercial buildings.

Health Effects. In low concentrations, formaldehyde irritates the eyes and mucous membranes of the nose and throat (NRC 1981b). The severity of the symptoms increases with concentration, but generally, effects are unlikely to occur at concentrations below 0.05 ppm (63 µg/m^3).

TABLE 3.7. Calculated Changes in Indoor Formaldehyde Concentration for Seattle (mg/m^3)[(a,b)]

Building Category	ASHRAE Standard 90A-1980 Design			Proposed Standard Design			Increment		
	Min Value	Typical Value	Max Value	Min Value	Typical Value	Max Value	Min Delta	Typical Delta	Max Delta
Small Office	0.020	0.080	0.670(c)	0.012	0.059	0.610(c)	-0.008	-0.021	-0.060
Medium Office	0.008	0.024	0.047	0.008	0.024	0.047	0.000	0.000	0.000
Large Office	0.006	0.019	0.032	0.006	0.019	0.032	0.000	0.000	0.000
Retail Store	0.005	0.015	0.026	0.005	0.015	0.026	0.000	0.000	0.000
Strip Store	0.007	0.031	0.269(c)	0.008	0.034	0.277(c)	0.001	0.003	0.008
Apartment	0.014	0.019	0.024	0.014	0.019	0.024	0.000	0.000	0.000
Hotel	0.005	0.014	0.024	0.005	0.014	0.024	0.000	0.000	0.000
Warehouse, Storage	0.015	0.079	0.923(c)	0.004	0.049	0.835(c)	-0.011	-0.031	-0.088
Warehouse, Office	0.021	0.078	0.633(c)	0.018	0.070	0.611(c)	-0.003	-0.008	-0.022
Assembly	0.006	0.020	0.109	0.006	0.019	0.105	-0.000	-0.001	-0.003
School Classrooms	0.004	0.019	0.197(c)	0.005	0.021	0.204(c)	0.001	0.002	0.007

(a) Formaldehyde Background = 0 mg/m^3.
(b) Formaldehyde ASHRAE Standard 62-1981 = 0.12 mg/m^3.
(c) Concentration exceeded ASHRAE Standard 62-1981 value. Fresh air ventilation may have to be increased to reduce indoor concentration. Minimum outdoor air requirements are based on ASHRAE Standard 62-1981.

Goyer (1981) noted that substances like formaldehyde are more noxious under some conditions than under others. Most of the information on the effects of formaldehyde stems from studies of residences, particularly mobile homes and houses with urea formaldehyde foam insulation (UFFI). In the absence of specific data, it was assumed that when formaldehyde concentrations in commercial buildings reach levels equal to or comparable to those found in mobile homes, individuals will react to formaldehyde much as they do in mobile homes.

Currently, no nonoccupational health standard for formaldehyde exposure exists for the United States. In 1979, ASHRAE recommended a 24-hour residential exposure limit of 0.20 ppm (250 $\mu g/m^3$) (NRC 1981b). In 1981, the recommended standard was reduced to 0.10 ppm (120 $\mu g/m^3$) (ASHRAE 1981). The lower exposure level is comparable to residential standards in West Germany (0.10 ppm), Denmark (0.12 ppm), and the Netherlands (0.10 ppm) (NRC 1981b). Anderson (1979) suggested that the standard for continuous formaldehyde exposure should be 150 $\mu g/m^3$ (0.12 ppm) or lower. He states that this level would protect all but those who are highly sensitive to formaldehyde against any adverse health effect and would protect most people against discomfort.

Studies show evidence that formaldehyde can be a carcinogen in animals. Sufficient evidence has not been provided to conclude that formaldehyde is teralogenic or carcinogenic in man, but Sterling (1985) stated that formaldehyde should be considered at least a potential carcinogen until shown otherwise.

Expected Impact on Formaldehyde Concentrations. Based on the buildings designed to the proposed standard and evaluated in this study and the stated insulating materials, formaldehyde concentrations in some commercial buildings are expected to be reduced slightly because of the proposed standard (see Table 3.7). The reduction is due to a shift from building materials that have a formaldehyde source term to materials that do not have a formaldehyde source term identified in the literature reviewed. As indicated previously, for this analysis building materials were selected based on cost and engineering factors. Although the combination of insulation materials selected for the proposed standard design may reduce formaldehyde concentrations slightly, concentrations of other organic compounds may increase slightly. As noted above in the general discussion of organic emissions, most structures in all the climate zones were predicted to have higher total organic emissions (including formaldehyde). As a component of the total organics, the specific changes calculated for formaldehyde emissions in Seattle were typical of the changes that would occur in other cities as well.

Conclusions. Some shifts in the expected levels of organic gases and formaldehyde may occur between the ASHRAE Standard 90A-1980 design and the proposed standard design. However, the direction of the shift, and the ultimate level of either type of substance directly depends on the building and insulation materials selected by the building architect. With the exception of warehouses, the incremental changes in organic compounds from the ASHRAE Standard 90A-1980 design to the proposed standard design are small in the test buildings. Organic concentrations calculated for the warehouse changed because of an increase in the amount of polystyrene insulation used, combined with a very low air exchange rate.

3.3.2.3 Combustion Products: Airborne Particles, CO, and CO_2

Several indoor air contaminants are produced by combustion processes in commercial buildings. This report examines three substances in detail--particulates, CO_2 and CO--and discusses several other combustion products.

The pollutants examined in the analysis in this section primarily are related to activities within or near the commercial building, and therefore, are not affected by the design standard or building material used. However, as discussed below, particulate concentrations may be affected by the use of the proposed standard because of proposed HVAC modifications which slightly alter the rate of air circulation. The concentrations estimated for each of these pollutants include a certain amount from the background, or ambient outdoor sources. These concentrations are noted in the footnotes of Tables 3.8 to 3.10, which list the calculated changes in combustion product concentrations for building designs that are representative of ASHRAE Standard 90A-1980 and the proposed standard.

In the commercial building environment, cigarette smoking and fossil fuel in boilers, stoves or ovens, and nonelectric vehicles are the main sources of

TABLE 3.8. Calculated Changes in Indoor Suspended Particulate Concentrations (RSP) ($\mu g/m^3$)

Building Category	ASHRAE Standard 90A-1980 Design			Proposed Standard Design			Increment		
	Min Value	Typical Value	Max Value	Min Value	Typical Value	Max Value	Min Delta	Typical Delta	Max Delta
Small Office	68	205(a)	342(a)	68	205(a)	342(a)	0	0	0
Small Office, 90% Filter	10	29	49	11	33	54	1	4	5
Medium Office	68	205(a)	342(a)	68	205(a)	342(a)	0	0	0
Medium Office, 90% Filter	9	28	46	9	28	47	0	0	1
Large Office	68	205(a)	342(a)	68	205(a)	342(a)	0	0	0
Large Office, 90% Filter	7	22	36	9	28	46	2	6	10
Retail Store	55	164(a)	274(a)	55	164(a)	274(a)	0	0	0
Retail Store, 90% Filter	18	53	89(b)	18	54	90(b)	0	1	1
Strip Store	55	164(a)	274(a)	55	164(a)	274(a)	0	0	0
Strip Store, 90% Filter	22	66	110(b)	24	71	118(b)	2	5	8
Apartment	30	84(a)	141(a)	30	84(a)	141(a)	0	0	0
Apartment, 90% Filter	6	17	29	7	19	31	1	2	2
Hotel	52	155(a)	258(a)	52	155(a)	258(a)	0	0	0
Hotel, 90% Filter	16	49	82(b)	18	55	92(b)	2	6	10
Warehouse Storage	13	40	67	13	40	67	0	0	0
Warehouse Storage, 90% Filter	0	0	1	0	0	1	0	0	0
Warehouse Office	68	205(a)	342(a)	68	205(a)	342(a)	0	0	0
Warehouse Office, 90% Filter	9	27	45	10	30	50	1	3	5
Assembly	46	138(a)	229(a)	46	138(a)	229(a)	0	0	0
Assembly, 90% Filter	25	74	123(b)	26	77(b)	129(b)	1	3	6
School Classrooms	10	31	52	10	31	52	0	0	0
School Classrooms, 90% Filter	3	8	14	3	10	16	0	2	2

Note: 1. RSP Background = 0 $\mu g/m^3$.
2. RSP NAAQ Standard = 75 $\mu g/m^3$.

(a) The computed concentration using minimum outdoor air ventilation and no filtration exceeded the NAAQ Standard value, indicating a need for filtration and/or increased fresh air supply.

(b) Concentration exceeded NAAQ Standard value. Fresh air ventilation may have to be increased to reduce indoor concentration. Minimum outdoor air requirements are based on ASHRAE Standard 62-1981.

TABLE 3.9. Calculated Changes in Indoor CO Concentrations (mg/m^3)

Building Category	ASHRAE Standard 90A-1980 Design			Proposed Standard Design			Increment		
	Min Value	Typical Value	Max Value	Min Value	Typical Value	Max Value	Min Delta	Typical Delta	Max Delta
Small Office	0.54	1.63	2.72	0.54	1.63	2.72	0	0	0
Medium Office	0.54	1.63	2.72	0.54	1.63	2.72	0	0	0
Large Office	0.54	1.63	2.72	0.54	1.63	2.72	0	0	0
Retail Store	0.44	1.31	2.18	0.44	1.31	2.18	0	0	0
Strip Store	0.44	1.31	2.18	0.44	1.31	2.18	0	0	0
Apartment	1.24	1.97	2.80	1.24	1.97	2.80	0	0	0
Hotel	0.41	1.23	2.06	0.41	1.23	2.06	0	0	0
Warehouse, Storage	0.11	0.32	0.54	0.11	0.32	0.54	0	0	0
Warehouse, Office	0.54	1.63	2.72	0.54	1.63	2.72	0	0	0
Assembly	0.42	1.17	1.92	0.42	1.17	1.92	0	0	0
School Classrooms	0.08	0.25	0.42	0.08	0.25	0.42	0	0	0

Note: 1. CO Background = 0 mg/m^3.
2. CO ASHRAE Standard 62-1981 = 5.5 mg/m^3.

TABLE 3.10. Calculated Changes in Indoor CO_2 Concentrations ($\mu g/m^3$)

Building Category	ASHRAE Standard 90A-1980 Design			Proposed Standard Design			Increment		
	Min Value	Typical Value	Max Value	Min Value	Typical Value	Max Value	Min Delta	Typical Delta	Max Delta
Small Office	1,665	1,666	1,667	1,665	1,666	1,667	0	0	0
Medium Office	1,665	1,666	1,667	1,665	1,666	1,667	0	0	0
Large Office	1,665	1,666	1,667	1,665	1,666	1,667	0	0	0
Retail Store	1,476	1,477	1,478	1,476	1,477	1,478	0	0	0
Strip Store	1,476	1,477	1,478	1,476	1,477	1,478	0	0	0
Apartment	1,360	1,376	1,393	1,360	1,376	1,393	0	0	0
Hotel	1,433	1,434	1,435	1,433	1,434	1,435	0	0	0
Warehouse, Storage	906	906	906	906	906	906	0	0	0
Warehouse, Office	1,665	1,666	1,667	1,665	1,666	1,667	0	0	0
Assembly	1,631	1,632	1,634	1,631	1,632	1,634	0	0	0
School Classrooms	3,617	3,617	3,618	3,617	3,617	3,618	0	0	0

Note: 1. CO_2 Background = 720 $\mu g/m^3$.
2. CO_2 ASHRAE Standard 62-1981 = 4500 $\mu g/m^3$.

combustion products. In addition, strong sources from outside the building (particularly vehicle exhaust) may be drawn into the building by the ventilation system. Pollutants from automobile exhaust may also be drawn into a building when an underground garage or parking area is present. On a mass basis, airborne particles, CO_2, CO and formaldehyde are the major components of sidestream cigarette smoke (i.e., from the burning tip) (Girman et al. 1982). Many other organic and inorganic constituents have also been identified (NRC 1981a) but are not evaluated in this analysis. Particulates, SO_2 and the NO_x are the primary pollutants produced by heating and cooking equipment in commercial buildings.

To determine the source terms of the sources of combustion product pollutants, the following assumptions were made:

- Based on national averages, about one-third of the population aged 17 or older smokes (NRC 1981a).
- The typical smoker smokes an average of 2 cigarettes per hour or 31 cigarettes over the course of 16 waking hours a day (NRC 1981a).
- In most commercial structures, local building codes usually require that spaces containing boilers and furnaces be vented directly to the outside. Accordingly, these strong sources were assumed to be removed from the building and did not contribute to contaminant levels in the recirculated air supply.
- Gas or wood stoves and ovens would in most types of buildings typically be vented separately.
- Calculations of combustion product levels in apartment buildings and assembly buildings (with kitchens), included gas kitchen appliances as a source.
- Heating and cooking equipment typically would not contribute to indoor combustion product concentrations in most commercial buildings, although in practice some portion of the pollutants may re-enter the building through the intake portals of the ventilation system or via natural ventilation. This possibility should be minimized by proper ventilation system design.

The discussion of particulates in this section is limited to suspended particulates created by combustion. Although varying amounts of dust may be present in commercial structures as a result of physical activity in the building, these particulates generally are large enough to remain suspended only temporarily or are mechanically filtered out by the ventilation system. Regardless of the source of suspended particulates in a building, either the total suspended particulate (TSP) levels can be examined in an analysis such as this, or only the respirable suspended particulate (RSP) portion. Because of the presence of mechanical ventilation and filtration systems in commercial buildings, this report focuses on RSP levels by assuming that particles larger than 3.5 μm are present only on a very short-term basis in most structures before they settle out of the air or are filtered out. In buildings where constant mechanical or physical activity is combined with the ongoing presence of large amounts of dust or combustion particles (warehouses in particular), the calculated levels of particulates may be underestimated.

RSP emission rates from tobacco smoking are estimated to be 10.8 mg per cigarette smoked (Girman et al. 1982), or about 335 mg of RSP per smoker per day. In measuring pollutants in public areas in commercial buildings, Elliot and Rowe (1975) found the TSP level from cigarette smoke to range from 0.224 to 0.481 mg/m^3. The emission rate of RSP used for this analysis combines an average rate of RSP from cigarettes prorated to the number of occupancy hours per day for smoker populations of about 10%, 33%, and 50% for low, average, and high values, respectively. These were applied only in sections where smoking is allowed. A zero source term is assumed in nonsmoking sections, with 10 to 30 mg/hr assumed from gas stoves where these appliances were assumed to be present. Commercial buildings typically use filtration systems of average efficiency to clean recirculated air. These systems typically remove only a very small fraction of the RSP generated in the building. Where the outdoor air of a locality falls below EPA standards for particulate content, however, higher efficiency filters at the intake point are generally required to clean outdoor before it is used as supply air.

For each cigarette smoked, 86 mg of CO and 80 mg of CO_2 are released. Assuming a rate of two cigarettes per smoker per hour, 1376 mg of CO and

1280 mg of CO_2 will be released by each smoker who is confined to a single building over a typical 8-hour working period. Human breath is also a significant source of CO_2. Normal respiration produces 36 mg (0.018 m^3) of CO_2 per hour per person (ASHRAE 1981).

Two other pollutants are major products of combustion in buildings: SO_2 and oxides of nitrogen (jointly referred to in most studies as NO_x). SO_2 is produced from the reaction of sulfur and oxygen during combustion. In the indoor environment, oil-fired furnaces generally produce more SO_2 than natural gas burners do, because oil contains more sulfur. However, contributions from fuel sources tend to be relatively small. At least three studies of various types of buildings have documented that indoor SO_2 levels are lower than outdoor concentrations (Berk et al. 1979; 1980a; 1980b). Nitrogen oxides are formed by the reaction of nitrogen and oxygen in the air during exposure to a flame. The relative concentrations of NO_x are a function of the flame's temperature, the air-to-fuel ratio, and the general operating characteristics of the burner. If gas furnaces, heater and stoves are not present in a building, or if such equipment is vented directly to the outside, the NO_x levels in the building are usually negligible. In buildings powered totally by electricity, indoor NO_x levels in the building are also usually minimal and have been found to be lower than ambient outdoor concentrations (Berk et al. 1979; Gleason 1980). Since the primary sources of these two contaminants are assumed not to be contributories to indoor air pollutants in this analysis, no estimates of SO_2 or NO_2 levels are included in the comparison of ASHRAE Standard 90A-1980 and the proposed standard.

Certain areas within a building may have higher levels of combustion-related pollutants than others. For example, relatively high particulate concentrations tend to accumulate in areas set aside for smoking (e.g., lounges and waiting rooms); high NO_x concentrations may occur in and near furnace rooms and kitchens where gas burners are used despite direct outside ventilation; and relatively high CO and CO_2 levels can develop in buildings with heavily used underground parking garages.

Health Effects. Although combustion-related pollutants can be produced by several indoor sources in commercial buildings, the health effects discussed here are based on modeled concentrations of airborne particles, CO_2, and CO attributable to tobacco smoke. Other strong sources, such as gas- or oil-fired boilers, are normally required to be separately vented to avoid mixing these pollutants with the return air for a building's occupied space. Occupant respiration is also assumed to be a source of CO_2. Background concentrations are assumed to exist for airborne particles, CO, and CO_2; these are noted in the tables showing projected changes.

The health effects caused by smoke and its constituents (particles, CO, and CO_2) vary according to the characteristics of the persons who inhale the smoke and according to certain aspects of the smoke-filled environment. Healthy persons may experience annoyance, irritation, breathing difficulty, and an increased incidence of lung cancer when subjected to cigarette smoke (NRC 1981a). Adults who have heart or lung disease or who are hypersensitive to the substances found in smoke may have severe reactions. In addition, there is some evidence of adverse effects of passive (sidestream) smoking on the respiratory health of children (NRC 1981a).

An EPA staff assessment (EPA 1982) of the levels of particulate matter based on long-term epidemiological studies shows that 1) decreased lung function and increased acute respiratory disease in children may occur at levels below 230 $\mu g/m^3$ British smoke (Lunn, Knowelden and Handyside 1967); 2) decreased lung function in adults may occur at TSP levels as low as 140 to 180 $\mu g/m^3$ (Bouhuys, Beck and Schoenberg 1978); and 3) some risk of increased respiratory disease and/or symptoms in adults may exist at levels of 110 to 180 $\mu g/m^3$ TSP (Bouhuys, Beck and Schoenberg 1978: Ferris et al. 1973).

Carbon monoxide combines with hemoglobin to form carboxyhemoglobin. Carboxyhemoglobin interferes with the oxygen-carrying capacity of blood, resulting in a state of tissue hypoxia. Acute CO poisoning may cause headaches, dizziness, drowsiness, nausea, vomiting, collapse, coma, and death. Initially the victim is pale; later the skin and mucous membranes may be cherry-red in color. Loss of consciousness occurs at about the 50 percent carboxyhemoglobin level. The amount of carboxyhemoglobin formed depends on the concentration and duration of CO exposure, ambient temperature, health, and metabolism of the individual. The formation of carboxyhemoglobin is a reversible process. Carbon monoxide at low levels may initiate or enhance harmful myocardial alterations in individuals with restricted coronary artery blood flow and decreased myocardial lactate production. Severe CO poisoning has been reported to permanently damage the extrapyramidal system, including the basal ganglia (Sittig 1985).

Although no indoor standard for respirable particles currently exists, the Environmental Protection Agency (EPA) does have an outdoor environmental standard of 260 $\mu g/m^3$ per 24-hour exposure (NAAQ Standard). The EPA has also set an annual average standard of 75 $\mu g/m^3$ for outdoor airborne particulate matter. The EPA standards are based on an extensive review of available information on the environmental effects of these outdoor pollutants. These reviews assessed the possible health effects caused by exposure to particulates typically found in outdoor air. However, cigarette smoke has a different chemical composition and different related health effects than typical outdoor airborne particulates. Outdoor air standards are therefore only an approximate measure of safe levels of particulates encountered in the indoor environment and were used in this report in lieu of comparable indoor air particulate standards.

Carbon monoxide exposures are limited by the current EPA standard (NAAQ) to an average of 9 ppm (10,000 $\mu g/m^3$) for an 8-hour period. The maximum (peak) rate allowable for any 1-hour exposure is 35 ppm. The ASHRAE guideline for indoor CO exposures is 5500 $\mu g/m^3$ (Standard 62-1981). No EPA standard for CO_2 has been set; the ASHRAE guideline for this pollutant in buildings is 4500 $\mu g/m^3$. Because EPA standards are for outdoor pollutant concentrations, they are not strictly comparable for indoor air quality. The standards are set by considering all known studies of health effects related to CO, including indoor studies when available.

In summary, information about the health problems caused by exposure to certain indoor combustion products is not conclusive. However, in test situations in which pollutant levels from combustion products exceeded EPA standards (usually because of cigarette smoking), symptoms such as eye irritation, coughing, and impaired breathing have been observed (NRC 1981a; Ferris 1978; Perera and Ahmed 1978; National Academy of Sciences 1979; World Health Organization 1978). Exposure to nonlethal levels of CO generally impairs the functioning of the oxygen transport system in the body.

Expected Impact on Combustion Product Concentrations. Smoker emission rates were discussed previously. Respirable particulate matter from cigarettes was computed for specified smoker fractions (see Appendix D) and included in the calculation of TSP. Tables 3.8, 3.9, and 3.10 show the calculated concentrations for RSP, CO and CO_2, respectively, for the ASHRAE Standard 90A-1980 design and the proposed standard design. For some ASHRAE Standard 90A-1980 design and proposed standard design, RSP is calculated to be high enough to require ventilation filters. Accordingly, the changes were also calculated using a 90% efficient ventilation filter for the test building in each category. Under the proposed standard, the building HVAC system in the proposed standard design reduces the ventilation flow (see Table 3.1). Because of this feature, filtration is not as effective and the level of RSP in filtered operations is estimated to increase slightly for the proposed standard design. In several cases, the calculated level of RSP reaches the criterion level of 75 $\mu g/m^3$ even after 90% efficiency filtration is added. However, these values are only moderately higher than the criterion value in most situations, and in all cases, the actual increment of proposed standard levels over the ASHRAE Standard 90A-1980 is very slight.

Conclusions. The emission rates of combustion products are independent of the design of a commercial building. Therefore, the levels of nonparticle combustion products (such as CO, CO_2 and NO_x) are not expected to vary in a given building as a result of the proposed standard instead of ASHRAE Standard 62-1981. The concentration of particulates, however, is predicted to be slightly higher in buildings constructed under the proposed standard, because of HVAC modifications that slightly reduce the rate at which air is passed through filters. The incremental increase in RSP levels is estimated to be very small except under the worst-case assumptions (with filtration) for large office buildings, assembly buildings and hotels. However, in these cases, the total average RSP is predicted to be well under the criterion value of 75 ($\mu g/m^3$).

CO and CO_2 concentrations were calculated to be the same in both the ASHRAE Standard 90A-1980 design and the buildings designed according to the proposed standard.

3.3.2.4 Summary of Incremental Changes in IAQ

Various pollutants are released continuously or intermittently within commercial buildings. An indoor air-quality computation model that uses specific pollution emission values (release rates) for selected materials was used to calculate pollutant concentration levels in the ten case-study buildings, based on ASHRAE Standard 90A-1980 design for baseline conditions and on a proposed standard design. Incremental pollutant concentrations were calculated for radon, formaldehyde, particulate matter, CO and CO_2 and are shown in Summary Table 3.11.

Radon. Calculated values for indoor air concentrations of radon indicate that changes in building insulation materials; heating, ventilation and air conditioning (HVAC); lighting; and service water design do not increase the level of radon concentration for the commercial building designed to the proposed standard over the building designed to ASHRAE Standard 90A-1980.

Formaldehyde. The computed concentrations of formaldehyde depend on materials chosen for the buildings designed under the proposed standard. In the ten test buildings designed under the proposed standard, there was a tendency to replace insulating materials that emit formaldehyde with materials that emit other organic compounds (primarily because of cost and insulating performance criteria). In most of the test designs, therefore, levels of formaldehyde present in buildings designed to the proposed standard are predicted to stay the same or decline slightly in comparison to those constructed according to ASHRAE Standard 90A-1980. (Correspondingly, higher organic concentrations may occur temporarily immediately upon completion of construction in the buildings designed to the proposed standard.) Formaldehyde concentrations in new strip stores and new school classrooms may have slightly elevated formaldehyde concentrations. The increase in formaldehyde is very small. Concentrations of both formaldehyde and other organic compounds can be very age-dependent. The

TABLE 3.11. Summary of Incremental Change in Indoor Air Quality Due to the Proposed Standard Commercial Buildings

	Radon (pCi/ℓ)		Formaldehyde (mg/m^3)		Particulate Matter W/HVAC Filter ($\mu g/m^3$)		Carbon Monoxide (mg/m^3)		Carbon Dioxide ($\mu g/m^3$)	
Category	Typical	Worst Case	Typical	Worst Case	Typical	Worst Case	Typical	Worst Case	Typical	Worst Case
Small Office	0	0	-0.021	-0.060	4	5	0	0	0	0
Medium Office	0	0	0	0	0	1	0	0	0	0
Large Office	0	0	0	0	6	10	0	0	0	0
Retail Store	0	0	0	0	1	1	0	0	0	0
Strip Store	0	0	0.003	0.008	5	8	0	0	0	0
Apartment	0	0	0	0	2	2	0	0	0	0
Hotel	0	0	0	0	6	10	0	0	0	0
Warehouse, Storage	0	0	-0.031	-0.088	0	0	0	0	0	0
Warehouse, Office	0	0	-0.008	-0.022	3	5	0	0	0	0
Assembly	0	0	-0.001	0.003	3	6	0	0	0	0
School Classrooms	0	0	0.002	0.007	2	2	0	0	0	0

calculated concentrations are based on emission rates for new insulation materials. Aging will considerably reduce the actual long-term average concentration expected to occur in commercial buildings designed under either ASHRAE Standard 90A-1980 or the proposed standard.

Combustion Products. The estimated concentration of TSP may increase slightly between the ASHRAE Standard 90A-1980 and the proposed standard designs because HVAC modifications in the latter tend to reduce the rate that air is passed through filters. (The volume of fresh air used to ventilate the building remains constant, however.) The incremental increase in TSP levels is small even under worst-case assumptions. However, in the test-design analysis, the total TSP for several building types (the retail store, the strip store, the hotel, and assembly building) are calculated under worst-case conditions to be over a value of 75 $\mu g/m^3$ for both the buildings designed according to ASHRAE Standard 90A-1980 and the buildings designed according to the proposed standard. No specific indoor air quality standard for TSP has been set, although the primary standard for outdoor air set by the National Ambient Air Quality Standards is 75 μ/m^3. The 75 μ/m^3 exceedence suggests that TSP sources such as tobacco smoking may need to be further controlled under worst-case conditions and/or ventilation rates need to be increased to reduce TSP concentrations. CO and CO_2 concentrations were estimated to remain unchanged when substituting the proposed standard design for the ASHRAE Standard 90A-1980 design.

3.3.3 Other Health and Safety Concerns

All design modifications to buildings, including most energy conservation retrofits, must conform to building safety codes. These codes reflect the informed judgment of trained, experienced professionals and are specifically designed to protect public health and safety. Laboratory testing is usually the basis for information on the expected frequency of adverse impacts for particular energy conservation measures. However, the probability that hazards manifested in the laboratory will actually occur in most buildings is uncertain, because combinations of factors not accounted for in the laboratory tests may be involved. In such cases, a conservative approach is usually adopted by the organizations responsible for these codes. That is, the level of standard generally adopted eliminates (or reduces to an acceptable degree) all of the likeliest hazards (or suspected hazards).

The energy-saving features that might affect building safety are discussed in a generic way only because buildings designed under either ASHRAE Standard 90A-1980 or the proposed standard must meet all relevant safety codes. The purpose of this section is to identify areas of possible concern associated with energy-saving design features. The design flexibility of the proposed standard should make it possible to compensate for any hazards not covered by existing codes.

3.3.3.1 Fire Hazards

Most of the safety issues associated with increased building energy efficiency center on fire hazard concerns. Table 3.12 summarizes various aspects of building design that could contribute to increased problems with fires, and their possible effect on fire safety. This table also provides examples of mitigation strategies to minimize those hazards.

The proposed standard does not require designs that conflict with any major existing fire codes. Compliance with the proposed standard should not result in new or radical design approaches but rather in a fine-tuning of existing design approaches to reduce whole building energy consumption. The concerns itemized in Table 3.12 apply equally to either ASHRAE Standard 90A-1980 or the proposed standard. As such, they are intended to emphasize that an awareness of the potential for fire hazards should be an integral part of any building design strategy.

3.3.3.2 Adequate Lighting Levels

Substantial energy savings for lighting were achieved in test buildings designed according to the proposed standard. Power for lighting was generally reduced through two types of design modifications: high-efficiency ballasts and lamps were substituted wherever fluorescent fixtures were specified, and the total number of lamps was reduced. Minimum light availability, as specified by procedures outlined by the Illuminating Engineering Society (IES), was maintained in all test rooms and spaces. The computer simulations run on the

TABLE 3.12. Energy Conservation Design and Fire Issues

Strategies for Energy Conscious Design	Effects on Fire Safety	Example Fire Protection Measures Needed to Compensate (with building designs evaluated separately)
1. Thick thermal insulation in building envelopes (i.e., high thermal resistance)	1. a. shortens time from fire ignition to "flash-over" b. widens extent of fire spread c. contributes to hotter, more destructive fire conditions	1. a. smoke detection devices b. automatic suppression systems
2. Additional thermal insulation in floor- and roof-ceiling constructions (i.e., resistance to heat transfer beyond fire-tested conditions)	2. could reduce fire resistance of assembly	2. a. additional membrane layer(s) b. plenum sprinklers
3. Thermal insulation around electrical wires, cables, etc. in wall and ceiling cavity air spaces	3. causes over-heating of conductor insulation	3. a. modify electrical system components b. smoke detection devices c. automatic suppression systems
4. Cellulose loose-fill thermal insulation (with water-soluble salts to reduce combustibility)	4. a. increases fire load in attics and plenums b. contributes to chemically induced corrosion of aluminum (and other metals)	4. a. improved fire-retardant treatments b. smoke detection devices c. automatic suppression systems
5. Tightly sealed windows and doors (and reduced areas of glazing)	5. a. change fire conditions from "fuel controlled" to hot, smoky "ventilation controlled" b. cause rapid smoke spread	5. a. envelope smoke and heat venting devices b. smoke control by mechanical air distribution systems
6. Variable-air-volume mechanical systems	6. difficult to achieve air-pressure barriers to smoke spread	6. a. additional duct flow volume capacity b. modify conventional system controls
7. Exterior shading devices (e.g., egg-crate, sculptured block, expanded metal)	7. block emergency escape to outdoors	7. a. well-marked operable panels b. automatic suppression systems
8. Siting on steep slopes (e.g., to achieve solar shading)	8. impedes fire apparatus access for rescue and suppression operations	8. a. modify slope conditions at site b. automatic suppression systems
9. Trees and vegetation adjacent to buildings (e.g., for wind control and solar shading)	9. a. flare-up of heavy concentration of dead, dry vegetation can ignite overhanging leaves, buildings, etc. b. limbs and boughs could extend too close to chimney outlets, incinerators, etc.	9. a. remove hazardous vegetative materials b. thin and prune trees surrounding building
10. Fan shutdown during night and weekends	10. reduces effectiveness of smoke control by mechanical air distribution systems	10. a. modify system controls b. provide continuous air pressure barriers in certain areas (e.g., corridors, shafts, stairwells)
11. Underground structures (or earth berming to eaves)	11. a. complicate escape strategy b. effects similar to 1 and 5	11. a. smoke detection devices b. automatic suppression systems c. smoke control systems

test buildings indicated that the proposed standard reduced (depending upon task activity) power density 20% to 30% without changing the quality of light in all ten test commercial buildings (PNL 1983). Substantial energy savings are also possible through daylighting and occupant-controlled lighting.

As long as adequate task lighting levels are maintained as required by building safety codes, the adverse impacts of lighting under the proposed standard should be very small. However, opinions vary as to whether the proposed standard provides the quality of light required for a balanced visual environment and for the varying needs of both younger and older people in commercial buildings. No definitive information is available on the question, and additional research is needed in this area. For example, high-pressure sodium (HPS) lamps are among the most energy-efficient lights available. However, their acceptance for indoor lighting is very controversial. The problems associated with HPS lamps are flicker, glare and color rendition. Some people may be sensitive to flicker, which may cause eye fatigue, or glare, which may cause discomfort or loss of visual performance. Occupant safety may also be affected because under HPS lighting, the color red is perceived as brown. Flicker can be alleviated by using improved high-frequency ballasts or by staggering HPS fixtures on a multiple-phase circuitry. The use of internally lit warning and danger signs instead of red paint is one alternative in alleviating safety problems from HPS. Thus, proper design and good judgment is a necessity when considering HPS lamps for indoor use.

3.3.3.3 Sanitation

Energy used for heating water may be conserved through several measures, most of which are routinely employed in the building industry and are governed by existing building and safety codes. The food service/dishwasher sanitation concerns discussed below are therefore mentioned only as a general area of potential concern that may be associated with building energy conservation. (In addition, providing adequately hot water for washing dishes used by the public is normally a building maintenance feature, rather than a design feature of energy conservation.)

Reducing hot water temperatures is one way to conserve energy. However, health code requirements may preclude reducing the temperature of hot water systems used to clean dishes and utensils in establishments serving food or beverages. Buildings in which a food service is not operated may also have kitchen facilities, including a dishwasher. In such cases, the temperature of the hot water system serving the dishwasher should not be reduced below that required for germ-free cleaning of dishes. For single tank, stationary rack dishwashers, the minimum recommended temperature is 165°F, although some dishwashers have heating elements that allow the use of lower water temperatures.

3.3.3.4 Toxic Fluids

With the advent of commercial applications of solar-powered heating and hot water heating, concerns arose that the toxic heat-transfer fluids often used in these devices could contaminate public drinking water or local waterways through leaks, spills or improper disposal of fluid. The recent availability of nontoxic heat transfer fluids make these problems avoidable, however. Both the ASHRAE Standard 90A-1980 and proposed standard encourage the use of renewable energy sources but do not mandate it. Therefore, the design flexibility implicit in the proposed standard, as well as careful selection of safe solar equipment, minimizes these potential problems.

3.4 OUTDOOR ENVIRONMENTAL IMPACTS

A building envelope may be made more energy efficient by adjusting any of several variables to achieve the proposed wall and roof standards, e.g., daylighting, solar heat gains, conduction gains and losses, and internal heat gains. A more energy-efficient building will reduce the energy needed to heat, cool, or light a building and therefore will reduce associated fuel production/emissions. However, environmental impacts associated with building energy use will decline, whereas the increased use of insulation and glass can be accompanied by greater manufacturing-related impacts.(a) This section reviews the effects of increased production of fiberglass insulation and glass on the outdoor environment. Although other forms of insulation are available and may

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(a) In some cases when cooling rather than heating is the object of envelope modifications, reductions in insulation may be required under the proposed standard.

be chosen based on cost considerations, more complete emissions data exist for the fiberglass industry and they will be used in this analysis.

The following discussion provides quantitative estimates of energy savings by building type and climate zone as well as estimates of average emissions levels for the insulation and glass industries. The amount of increased production of pollutants (if any), the ability to control additional emissions, and the net outdoor environmental impacts are discussed qualitatively because of the uncertainty associated with the site-specific variables.

3.4.1 Estimated Energy Savings Due to the Proposed Standard

As discussed earlier, ten actual commercial buildings were selected by a team of energy conservation experts to test the effects of modifying ASHRAE Standard 90A-1980. These buildings were selected to be broadly representative of the types of construction expected to occur in the future, but they were not expected to be strictly representative of a particular type of construction. The proposed standard was applied to the ten commercial test buildings across five climate zones.

The project test results indicated that substantial energy savings should result across the range of commercial building categories if the proposed standard is implemented. Office buildings averaged about 19% total savings, while most other buildings were in the 10% to 15% savings range. The largest energy savings were realized by reduced lighting energy consumption and corresponding reductions in space cooling loads. Reductions in building envelope transmissivity and in the solar load on windows through shading significantly reduced cooling requirement peaks, which permitted size reductions in the heating and cooling systems. Because these data were generated from test buildings, energy savings will vary with different approaches by individual builders in dissimilar geographic locations. Table 3.13 lists the total estimated annual energy savings that would result from the proposed standard for each type of building under consideration. These numbers reflect selected fuel mode splits (electricity/gas), test buildings, and selected city locations.

TABLE 3.13. Estimated Annual Aggregate Energy Savings from the Proposed Standard(a)

Building Type	Electricity Savings		Gas Savings (billion Btu)
	Billion Btu	Average Megawatts(b)	
Small Office	57	2	1
Medium Office	529	18	13
Large Office	57	2	10
Large Retail	2593	87	0
Small Retail	462	15	23
Assembly	4031	135	-474(c)
Warehouses	1396	47	1016
Educational	333	11	13
Hotel	26	1	19
Apartment	1	--	--

(a) The selected fuel split between electricity and gas does not reflect the national proportion of fuel, but rather the fuel split used by the test buildings.
(b) Based on 3,412 Btu/kWh.
(c) A reduction in solar loads on the windows eliminated a significant source of heat, so additional gas was needed to replace that loss.

3.4.2 Power Plant Emissions Levels Associated with Energy Savings

The estimated energy savings from the use of the proposed standard would reduce emissions from fuel use but would increase emissions from the increased use and manufacture of building materials.

Table 3.14 lists the estimated total annual reduction in emissions attributable to the proposed standard at a coal or nuclear power plant. The reduction is based on emissions levels developed for the Environmental Assessment of Energy Conservation Opportunities in Commercial-Sector Facilities in the Pacific Northwest [Bonneville Power Administration (BPA) 1982] and scaled to the data from Table 3.13. These data are national totals; spread out over the nation's power plants, incremental decreases in annual plant emissions would be small in most cases.

TABLE 3.14. Estimated Annual Total Avoided Impacts on Land, Water, and Outdoor Air Quality from the Proposed Standard[(a)] (BPA 1982)

Area of Impact	Coal Plant	Nuclear Plant
Solid Waste		
Fly Ash (tons)[(b)]	69,000	ND[(c)]
Bottom Ash (tons)[(b)]	17,000	ND
Water Use (Acre-feet)	22,000	25,000
Water Emissions		
Biological Oxygen Demand (lb)	525	25
Chemical Oxygen Demand (lb)	2,000	ND
Total Suspended Solids (lb)	17,000	ND
Non-Ferrous Metals (lb)	2,100	ND
Sulfates (lb)	800	ND
Boron (lb)	ND	2,500
Acids (lb)	ND	76
Oil and Grease (lb)	130	51
Air Emissions		
Airborne Particles (tons)	370(320)[(d)]	ND
Sulfur Dioxide (tons)	1,600(14,000)[(d)]	ND
Nitrogen Oxides (tons)	7,500	ND
Hydrocarbons (tons)	180	ND
Carbon Monoxide (tons)	500	ND
Waste Heat (trillion Btu)	15	20
Radioactive Products		
Liquid Discharge (curies)	ND	0.1
Liquid Waste (gal)	ND	110,000
Solid Waste (curies)	38[(e)]	45,000,000
Atmospheric (curies)	0.16	210,000

(a) Values represent the level of impact per 318 average annual megawatts of electricity produced.

(b) Estimate based on use of dry bottom boiler at a coal plant.

(c) ND = not determined, estimate is very small or not applicable.

(d) Value in parentheses is derived from Dvorak et al. (1978); the other number is estimated by DOE (1979).

(e) In fly ash not retained by electrostatic precipitators.

3.4.3 Emissions Levels Associated with the Manufacture of Glass and Fiberglass Insulation

The level of outdoor environmental impacts from increased production in the glass and insulation industries is not easily quantifiable for several reasons:

1. The size and emissions control capability of the individual plants that provide building materials will differ.
2. Regional building requirements not accounted for in the test process need to be considered.
3. Site-specific building codes have to be considered.
4. Varying approaches by the building contractors to achieve certain envelope standards must be considered (including both materials and structure options). For example, in some cases insulation may be modified by a reduction in insulation thickness.

During the manufacture of glass products such as windows, doors, and sky lights, the melting unit process is by far the most energy-intensive. According to A. D. Little (1976), air pollution emissions from a glass melting furnace may include particulates, nitrogen oxides, sulfur oxides, and minor emissions of fluorides, arsenic, lead and a few others. Water pollution is associated with a wet scrubber used on the furnace and operated in a recycle mode with a small purge stream. The purge stream will contain high concentrations of particulates, sulfites, sulfates, and trace metals such as selenium, boron, and arsenic. The solid wastes from the melting process are sludge from the water treatment plant and dust accumulating in a fabric filter. Table 3.15 summarizes the emission rates associated with the glass melting process per ton of glass produced.

Table 3.16 gives an indication of the number of panes of glass required for the 10 test design buildings in five different climates for the proposed standard design. The number of windows in each building does not change between ASHRAE Standard 90A-1980 and the proposed standard, but the glazing may change from single to double or triple pane. An assessment of the impact of

TABLE 3.15. Glass Melting Furnace Emissions Factors Without Controls (A. D. Little 1976)

Species	Emission Rate (lb/ton of glass produced)
NO_x	8.0
SO_x	3.0
Particulates	2.0
CO	1.0
Hydrocarbons	0.2
Arsenic	0.6
Selenium	0.03
Antimony	0.1
Cl_2 or HCl	0.1
Fluorides (opal glass)	22.0
Fluorides (soda-lime glass)	0.1
Lead	10.0
Borates	20.0

the proposed standard on glass production levels (and subsequent emissions levels) would require correlating these figures to the square footage of glass in each building type and then projecting them to national levels. The data needed to make these determinations have not yet been developed, but the impact on national glass production levels is likely to be slight because the volume of federal sector construction is very small in proportion to the national total.

The construction industry uses insulation primarily composed of wool fiberglass. According to Sittig (1975), the major air pollution emissions from the fiberglass manufacturing processes are particulates from the glass melting furnace, the fiber forming line, the curing oven, and the product cooling line as well as gaseous organic emissions from the forming line and curing oven. Water pollution in an insulation fiberglass plant results from boiler blowdown, water treatment backwashes, chain cleaning water, and water sprays used on the exiting forming air. Table 3.17 provides estimates of average emissions factors for the production of fiberglass insulation. These figures are only

TABLE 3.16. Number of Panes of Glass Required to Comply with the Proposed Standard

Test Building	Location	ASHRAE 90A-80	Proposed Standard	% Change
Small Office	1 Seattle	1	2	100
	2 El Paso	1	1	0
	3 Houston	1	2	100
	4 Milwaukee	1	2	100
	5 Wash. D.C.	2	3	50
Medium Office	1	1	2	100
	2	1	1	0
	3	2	2	0
	4	2	2	0
	5	2	3	50
Large Office	1	1	1	0
	2	1	1	0
	3	1	2	100
	4	1	2	100
	5	2	2	0
Retail Store (anchor)	1	1	1	0
	2	1	1	0
	3	1	1	0
	4	1	1	0
	5	1	1	0
Strip Store	1	1	1	0
	2	1	1	0
	3	1	1	0
	4	1	1	0
	5	1	2	100
Apartment	1	1	1	0
	2	1	1	0
	3	1	1	0
	4	1	1	0
	5	1	2	100
Hotel	1	2	2	0
	2	2	2	0
	3	2	2	0
	4	2	2	0
	5	2	2	0
Warehouse	1	1	1	0
	2	1	1	0
	3	1	1	0
	4	1	1	0
	5	1	1	0
Assembly	1	1	1	0
	2	1	1	0
	3	1	2	100
	4	1	2	100
	5	2	2	0
School	1	1	1	0
	2	1	1	0
	3	1	1	0
	4	1	1	0
	5	1	2	100

TABLE 3.17. Fiberglass Manufacturing Emissions Factors Without Controls (Sittig 1975)

Species	Emission Rate (lb/ton of glass produced)
NO_x	8.3(a)
SO_x	19.5(a)
Particulates	112.8(a)
CO	2.5(a)
Fluorides	0.3(a)
Phenol	0.92(b)
Aldehyde	3.3(a)
Suspended Solids	5.8(c)
Biological Oxygen Demand (BOD)	8.8(c)
Chemical Oxygen Demand (COD)	37.4(c)
Dissolved Solids	32.0(c)

(a) Wool fiberglass production (primarily insulation).
(b) Wool fiberglass production plus insulation fiberglass plants.
(c) Insulation fiberglass plants.

averages; specific plant emissions will vary because of methods of water treatment and thermal and time factors affecting individual processes. Sittig (1975) indicates that water usage and raw waste loads cannot be practicably related to production levels or techniques. On the other hand, particulate emissions from a glass melting furnace (used both in glass and fiberglass insulation manufacture) can be affected by basic furnace design, type of fuel, raw material size and composition, and type and volume of the furnace heat recovery system.

As with the glass industry, projecting changes in production levels of insulation is difficult. Complicating the issue further is that in many cases the type of insulation used will change between ASHRAE Standard 90A-1980 design and the proposed standard design because of cost considerations (see Table 3.5). The assessment of the net impact on industry emissions from producing various types of insulation has not been undertaken. However, Sittig

(1975) indicates that production changes would affect primarily the volume of particulates. The current particulate emission rate of 112.8 pounds per ton of fiberglass produced probably would not be substantially altered because of changes required by the proposed standard.

3.4.4 Conclusions

Energy savings associated with more energy-efficient buildings would reduce the level of outdoor pollutant emissions from oil, natural gas, and electricity use. Improving the efficiency of the building envelope would reduce fuel requirements but may require additional production of insulation and glass, resulting in possible increases in manufacturing-related emissions. The magnitude of the improvement in outdoor environmental quality from reduced fuel use as well as the degradation from possible increased materials manufacture in order to comply with the proposed standard is very small. Ambient land, air, and water quality standards or industry's ability to comply with them should not be substantially affected because any additional emissions would be an extremely small part of current emissions rates. While it was not possible to calculate net effect on the outdoor environment in this analysis, it is likely to be positive because reductions in pollutant emissions due to decreases in energy consumption will occur over the life of a building (assumed to be 20 years). Manufacturing-related increases in emissions, however, are incurred only once--during construction--for any given building.

3.5 ECONOMIC EFFECTS

The economic analysis conducted to determine the impact of requiring federal agencies to design their new commercial buildings according to the proposed standard concluded that no major impacts are expected to occur (Roop and King 1985). The analysis addressed only economic impacts that could result from federal agency compliance. The impacts that may occur as a result of voluntary compliance by the private sector were not calculated.

According to F. W. Dodge construction data (proprietary data of construction activity),(a) the average federal construction of commercial buildings

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(a) Purchased from F. W. Dodge, a division of McGraw-Hill, New York, New York.

during 1967-1980 period was 2.62% of the nation's total commercial construction volume. Whereas this construction is a small proportion of the total, it nonetheless accounts for more than a $100 million impact on the nation's economy.

As in the environmental assessment, only the proposed standard and the ASHRAE Standard 90A-1980, which is the baseline, were analyzed in detail in the economic analysis. The building categories used in the economic analysis were again limited to those for which design and computer simulations of energy use and life-cycle-cost analysis had been conducted for the DOE. The test buildings were analyzed over a 20-year time horizon, with life-cycle costs calculated for each building category in 5 locations. The life-cycle costs were aggregated to the national level using federal sector construction forecasts. The aggregate net benefits (or the reduction in total life-cycle cost at the national level) were then used in a macroeconomic model of the U.S. to determine the indirect impact of the proposed standard.

The impact of the proposed standard was determined in several steps: 1) the direct net benefits were estimated as noted above; 2) federal expenditures were assumed to shift by the change in the net benefits; and 3) these changes in federal expenditures were simulated in a dynamic, input/output macroeconomic model of the U.S. economy. Changes in net benefits were estimated using regional forecasts of commercial building construction and the net present value of the savings (as calculated by the life-cycle cost method) that would occur if the proposed standard were adopted for the 10 building categories. Government demand for electricity, gas, building construction and personal services (for operation and maintenance) were reduced by the change in net benefits, offsetting increases in government expenditures elsewhere. The macroeconomic model then simulated the effect of these changes in government demand on the economy. The macroeconomic changes caused by adopting the proposed standard were compared to the ASHRAE Standard 90A-1980 case to determine the interindustry shifts in output, employment and other economic effects. No significant effects were discernible, even when the entire cumulative changes over the 20-year period of analysis were applied to a single year's forecast. Thus, there appears to be no major consequence to any particular industry or to the economy as a whole as a result of adopting the proposed standard.

The primary national effects of adopting the proposed standard by federal agencies would be to reduce federal government energy expenditures by $141.9 million ($1982, net present value terms) over the 20-year period (electricity expenditures would decline by $140.6 million, and natural gas costs would decline by $1.3 million). In physical units, 9.4 trillion Btu of electricity (or 318 average MW) and 0.6 trillion Btu of gas would be saved. O&M costs would decline by $20.3 million and capital expenses by $3.4 million. Capital costs are reduced primarily from the savings achieved by down-sizing heating and air-conditioning equipment as the energy efficiency of the building is increased.

Regional impacts are also expected to be small. With the exception of the hotel building in Seattle, where capital costs are among the highest and energy is the cheapest of the regions examined, none of the costs calculated for the test buildings increased as a result of the standard. Buildings constructed in all regions under the proposed standard experience reduced costs of ownership and operation.

Imposing the proposed standard is expected to directly affect only gas and electric utilities, and the construction and the building maintenance service industries. The most significant effects are predicted for electric utilities, yet their output was predicted to change less than 0.1% of the total when the entire effect of the proposed standard was simulated to occur in a single year. The overall annual impact in any of the industries is negligible.

The macroeconomic changes that would occur as a result of imposing the standard on federal building construction are modest. Real (in 1982 dollars) Gross National Product (GNP) does not change measurably, although nominal-fixed investment does decline by about $270 million (less than 0.02%). Total output for all industries is reduced by about $140 million, almost the same magnitude of change in constant (1982) dollars as the net benefits. This decline in output occurs as a result of shifts from capital-intensive industries (primarily utilities) with some offsetting increase in output in more labor-intensive industries, so that employment actually increases by about 1,500 jobs (about

+0.002%). From a macroeconomic perspective, these changes are so small that they can all be considered inconsequential; the largest change is in investment in structures, which is less than 0.02%. The measurable change in output, $140 million, is less than 0.002% (Roop and King 1985).

3.6 INSTITUTIONAL EFFECTS

The NEPA legislation requires in the EA a discussion of the possible institutional impacts that might result from implementing a significant federal action. Although it is unlikely that this issuance will be considered a significant federal action, institutional issues have been included in this assessment.

This discussion basically addresses the disruptions, if any, that a federal agency or institution might experience as a result of adopting this standard. The effect on any given agency depends on its annual volume of commercial building construction. Therefore, this section reviews only the standards to which federal buildings are currently designed and any general changes that might be incurred by an agency when it adopts the proposed standard.

3.6.1 Current Federal Design Standards

Although 24 federal agencies have the authority to construct their own buildings, only 8 of these account for 98% of all federal building design and construction activities:

1. Department of Energy
2. Department of Defense
3. National Aeronautics and Space Administration
3. U.S. Postal Service
4. Veterans Administration
5. General Services Administration
6. Department of Housing and Urban Development
7. Department of Health, and Human Services

The current federal policy as outlined in the Federal 10 Year Buildings Plan (DOE 1983) requires federal agencies to use industry standards whenever practical and possible. In this plan DOE has designated ASHRAE Standard 90A-1980 as the efficiency standard for new federal buildings, with the provision that the DOE life-cycle cost methodology be used to comply with the requirements of Section 545 of National Energy Conservation Policy Act, Pub. L. 96-619 (1978).

ASHRAE Standard 90A-1980 is usually applied as a component performance standard. It contains thermal efficiency requirements for walls and roofs based on heating and cooling degree days, efficiency requirements for the HVAC equipment, standards for the amount of fenestration, lighting power budgets, and other provisions covering the major building features that influence energy flow.

Federal agencies may develop and use their own standards for new or existing buildings if these standards are as stringent as the requirements of ASHRAE Standard 90A-1980 and as long as their analysis indicates that the retrofit measures are effective based on their life-cycle estimates.

In 1982, pursuant to Subtitle H of the Energy Security Act, Pub. L. 97-62 (1980), the DOE formally requested that federal agencies begin to use ASHRAE Standard 90A-1980, the newly revised and updated version of ASHRAE Standard 90-75. At the time this document was initiated, all of the 8 agencies listed above were using ASHRAE Standard 90A-1980 or their own equivalent standard for their new commercial building construction.

3.6.2 The Proposed Standard

The standard being proposed by the DOE at this time is not radically different in format from what is already being used by the federal government or recommended to private sector designers by the ASHRAE standard-setting organization. Sections 4 through 9 of the proposed standard provide a component performance standard with prescriptive levels for each of several components, such as the building envelope, the lighting system, and the HVAC equipment and system. Section 10 provides an alternative to the application of the specific criteria of Sections 4 through 9.

One fundamental difference between the proposed standard and ASHRAE Standard 90A-1980 is in its organization. Unlike ASHRAE Standard 90A-1980, the proposed standard specifies that the illumination system be designed before the requirements for the exterior envelope are calculated. This is an important difference because the results from the illumination section may now be entered into the exterior envelope calculations. The other major changes occur in the illumination system requirements and the exterior envelope requirements. The proposed standard requires that lighting power densities generally be reduced by 25% and that task lighting be used wherever possible when supplementary light is needed. The most extensive changes in exterior envelope design basically upgrade requirements for thermal efficiency: walls must now meet three separate criteria for peak cooling, annual cooling, and annual heating.

Other changes affect the design of HVAC systems and service water requirements, but these changes merely reflect the continuing technical improvements in the field.

3.6.3 Impacts

The basic format of ASHRAE Standard 90A-1980, as the nationally recognized component performance standard for energy conservation, has not been changed in the proposed standard. Instead, a format was chosen that would be substantially compatible with existing standards to facilitate implementing the proposed standard in federal agencies, as well as to provide an easily adopted model for private sector building designers.

The changes to the illumination system were made primarily to simplify the calculation and compliance verification process from the existing standards. With these changes, the designer calculates the power density budget for an activity area instead of room by room. This change results in many fewer calculations.

Some of the exterior envelope compliance procedures may have increased in complexity. This complexity, however, should not affect designers of federal buildings, who already have to perform life-cycle-cost analyses and who have ready access to computers, microcomputers, or programmable calculators.

The director of each federal agency involved in constructing any new commercial building will have to adopt procedures to ensure that all construction meets or exceeds the proposed standard. Agencies periodically issue administrative rulings that change or upgrade existing requirements. This is normally done without any disruption to a project or the agency. Therefore, the adoption and enforcement of the proposed standard by federal agencies is not expected to have any disruptive impact on the way they design new commercial buildings. For these reasons, it is unlikely that federal agencies will experience any adverse institutional effects on administrative procedures or building design practices that they already use when designing new commercial buildings.

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APPENDIX A

DEVELOPMENT AND TESTING OF THE PROPOSED STANDARD

APPENDIX A

DEVELOPMENT AND TESTING OF THE PROPOSED STANDARD

The Energy Conservation for New Buildings Act of 1976 (Title III of Publ. L. 94-385) as amended, requires the DOE to issue energy conservation standards for the design of new commercial and residential buildings. The standards will be mandatory only for the design of new federal buildings and will serve as voluntary guidelines for the design of new non-federal buildings. A multipart report documents the development and testing of the proposed standard that will serve as the basis for the Congressionally mandated conservation standard for new commercial buildings. The report, entitled Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings, was issued in 4 volumes consisting of 40 separate publications in 1983 by Pacific Northwest Laboratory, Richland, Washington. The 4 volumes are briefly described below, followed by a listing of reports (Table A.1).

- Volume I contains the text of the recommendations for the conservation standard. Appendix A to Volume I compares (on a line-by-line basis) the recommendations with ASHRAE Standard 90A-1980, which was the starting point for developing the recommendations.
- Volume II describes the standard development process and contains the rationale for the general approach and specific criteria contained within the recommendations. Appendices in Volume II document the project research conducted in support of recommendations for the exterior envelope, HVAC systems and equipment, and lighting sections.
- Volume III describes the project's testing process and summarizes the energy and economic implications of applying these recommendations to ten test buildings across five climates. It is supported by appendices that document input data, assumptions, and computer codes used in the testing process.

- Volume IV is composed of 30 separate reports that contain detailed background information on the testing process and results. For each of the ten test buildings, three reports record the testing process: one details building configuration and cost estimates, one presents representative energy (DOE-2.1B) analyses, and one presents life-cycle cost estimates.

TABLE A.1. Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings

Report Number		Volume	Title
PNL	DOE		
4870-1	DOE/NEB-0051	Volume I	Text of Recommendations
4870-2	DOE/NEB-0051/1	Appendix A	Side-By-Side Comparison of the Recommendations and 90A-1980
4870-3	DOE/NEB-0051/2	Volume II	Description of the Development Process
4870-4	DOE/NEB/0051/3	Appendix A	Envelope Research Documentation
4870-5	DOE/NEB/0051/4	Appendix B	HVAC and Miscellaneous Envelope Research Documentation
4870-6	DOE/NEB/0051/5	Appendix C	Lighting Research Documentation
4870-7	DOE/NEB/0051/6	Volume III	Description of the Testing Process
4870-8	DOE/NEB/0051/7	Appendix A	Testing Assumptions and Inputs
4870-9	DOE/NEB/0051/8	Appendix B	Envelope Compliance Code Documentation
4870-10	DOE/NEB/0051/9	Appendix C	Life-Cycle Cost Code Documentation
		Volume IV-A	Documentation of Test Results: Small Office Building (Branch Bank)
4870-11	same(a)		Part 1: Plans, Elevations, Photos, Compliance-Check Data Sheets, Cost Estimate Data Sheets
4870-12	same		Part 2: Selected DOE-2.1B Input and Output Files
4870-13	same		Part 3: Life-Cycle Cost Results
4870-14, 15, 16	same	Volume IV-B	Documentation of Test Results: Medium Office Buildings (3 parts)
4870-17, 18, 19	same	Volume IV-C	Documentation of Test Results: Large Office Building (3 parts)

(a) The DOE number is the same as the PNL number.

TABLE A.1. (contd)

Report Number			
PNL	DOE	Volume	Title
4870-20, 21, 22	same	Volume IV-D	Documentation of Test Results: Retail Store (Anchor Store) (3 parts)
4870-23, 24, 25	same	Volume IV-E	Documentation of Test Results: Strip Store (3 parts)
4870-26, 27, 28	same	Volume IV-F	Documentation of Test Results: Apartment House (3 parts)
4870-29, 30, 31	same	Volume IV-G	Documentation of Test Results: Hotel (3 parts)
4870-32, 33, 34	same	Volume IV-H	Documentation of Test Results: Warehouse (3 parts)
4870-35, 36, 37	same	Volume IV-I	Documentation of Test Results: Assembly Building (Church) (3 parts)
4870-38, 39, 40	same	Volume IV-J	Documentation of Test Results: School (3 parts)

APPENDIX B

DESCRIPTION OF TEST BUILDINGS

APPENDIX B

DESCRIPTION OF TEST BUILDINGS

Commercial buildings[a] differ widely in their construction, use, operation, and energy consumption, and therefore in their probable response to energy conservation measures. To account for major differences among structures, commercial buildings were separated into ten categories according to their function or intended use and were configured for five climate zones:

- Small Office
- Medium Office
- Large Office
- Large Retail Store (Anchor Store in a mall)
- Strip Store
- Apartment
- Hotel
- Warehouse
- Public Assembly
- School.

Each building evaluated is briefly described below. A more complete description of each building can be found a series of reports titled Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings, Volumes I, II, III, and IV (PNL 1983).

(a) The federal government builds and uses many different types of buildings, many of which are classified as commercial structures by design and generic use. Obviously, there are major differences between the federal and private sectors in the actual activities carried out in "commercial" buildings. Nevertheless, the general design, construction and use of these types of buildings are similar enough to allow the use of private sector buildings as prototypes for the testing of the proposed standard (see the Methodology section of Chapter 3).

B.1 SMALL OFFICE BUILDING

The small office building evaluated is a single-floor 2500-ft^2 branch bank (50 ft x 50 ft), constructed in Guilderland, New York, in 1981 (Figure B.1). It has a floor-to-roof height of 16 feet and is of wood frame construction with brick veneer. The building is roughly 50% glass on the north and south sides, with 10% glass on the west and 3% on the east. A large overhang on the east side of the building covers the drive-up teller's window. The structure is of above-average construction quality and was designed for 19 occupants (employees).

The building is operated on a typical office schedule: 8 a.m. to 6 p.m. on weekdays with minor night use and about 30% of typical occupancy on Saturdays (daytime only). The building is closed on Sundays and holidays.

B.2 MEDIUM OFFICE BUILDING

The medium office building evaluated was built in Farmington, Connecticut, in 1973 (Figure B.2). It contains 49,500 ft^2 on 3 floors, with a steel frame superstructure and exterior walls of 4-inch precast concrete panels. Floor-to-floor height is 12 feet. There is 1 hydraulic passenger elevator and 2 internal stairways. The first floor is partially bermed.

About 36% of the wall area is glass, with fairly constant proportions on all sides and all floors. The first-floor windows slope into the building at 57° (like a greenhouse), and the second-floor windows are shaded by the 5-foot overhang of the top floor. The first floor also receives some shading from the top floor. Aside from this unusual glazing, it is a typical medium-sized office structure, of above-average construction quality. It is occupied by 330 people, all involved in office activities on a basic 5-day work-week schedule.

B.3 LARGE OFFICE BUILDING

The large office building selected for project evaluation was built in Indianapolis, Indiana, in 1981 (Figure B.3). As constructed, it is part of a

FIGURE B.1. Small Office Building

FIGURE B.2. Medium Office Building

FIGURE B.3. Large Office Building

larger complex that included attached low-level retail stores and an underground garage. For this effort, only the office tower complex itself was modeled, consisting of 38 floors plus 2 basement levels. With approximately 18,000 ft^2 per floor, the tower is a flattened hexagon in cross section that flares out to a larger base at the bottom floors. Floor-to-floor height averages 13 feet, 6 inches. The building is constructed of steel frame with limestone cladding and is of above-average quality construction. It houses 16 electric and hydraulic elevators. The tower is about 25% glass, equally spaced around the 6 sides.

The building is operated on a typical office schedule: 8 a.m. to 6 p.m. on weekdays with some evening work and about 30% occupancy on Saturdays (no evenings).

B.4 LARGE RETAIL STORE

The retail store evaluated was a high-quality department store that serves as an anchor store for a mall shopping center. It was built in Atlanta, Georgia, in 1975 (Figure B.4). The building is a 2-story structure with an average floor-to-floor height of 19 feet. It has an area of 164,200 ft^2; 82% is used for merchandising and office space and 18% is used for stock and storage. Construction is steel frame with masonry skin. The building has very little glass, no display windows, only 8-foot wide glass entrance doors and a strip of small windows on the second floor office area. This amounts to about 10% glass on the north and west sides and 3% on the east side. There is no glass on the south side, where it opens into the mall area. (Contact with the mall was simulated as an adiabatic surface for thermal modeling purposes.) The building is of above-average construction quality.

Operating hours are simulated as 10 a.m. to 10 p.m. on Saturdays and weekdays, and 10 a.m. to 6 p.m. on Sundays and holidays. Employee schedules are somewhat longer. Maximum occupancy is 2008.

B.5 STRIP STORE

The small retail store evaluated was composed of two units (end and adjacent unit) of a strip shopping center built in Multnomah County, Oregon, in

FIGURE B.4. Retail - Anchor Store

1978 (Figure B.5). The units are single-story (18 ft) with a gross area of 11,760 ft^2 and wood-frame construction with cedar siding. Maximum occupancy is 286. There is about 35% glass on the southern and western exposures, with no glass on the eastern and northern exposures.

Operating hours are 10 a.m. to 10 p.m. 6 days per week, with a reduced schedule of 10 a.m. to 8 p.m. on Sundays and holidays.

B.6 APARTMENT

The multifamily building selected for project testing was built in Edina, Minnesota, in 1977 (Figure B.6). It is a 9-story structure built in the shape of an "H," with underground parking. It consists of 416,776 ft^2 (excluding parking), of which 362,736 ft^2 are residential living quarters, and 54,040 ft^2 are comprised of public areas and corridors. The building is constructed of cast-in-place concrete columns and flat slabs with post-tensioned steel reinforcing. North and south exposures have about 27% glass; east and west exposures have about 20% glass. The building was designed as an upper-middle class retirement home for 1310 elderly people.

B.7 HOTEL

The hotel evaluated is a large convention-type hotel built in Bellevue, Washington, in 1981 (Figure B.7). The 10 floors include 315,000 ft^2 dedicated to public areas (30%), guest rooms (65%), and service areas (5%). It is built on a long north/south axis with large eastern and western exposures. The building is 70% glass on the west (including a large sloped atrium/lobby), 54% glass on the east, and only 10% southern and 4% northern glass. The construction is reinforced concrete frame with a 9-foot floor-to-floor height. The dining and lounge areas have a 20-foot height and the lobby/ atrium has a 45-foot average height. The building has 7 electric and hydraulic elevators.

Maximum occupancy is 2900. Room occupancy is high at night and minimum during the daytime hours, with meeting rooms showing the inverse. Office spaces show round-the-clock use, though reduced at night.

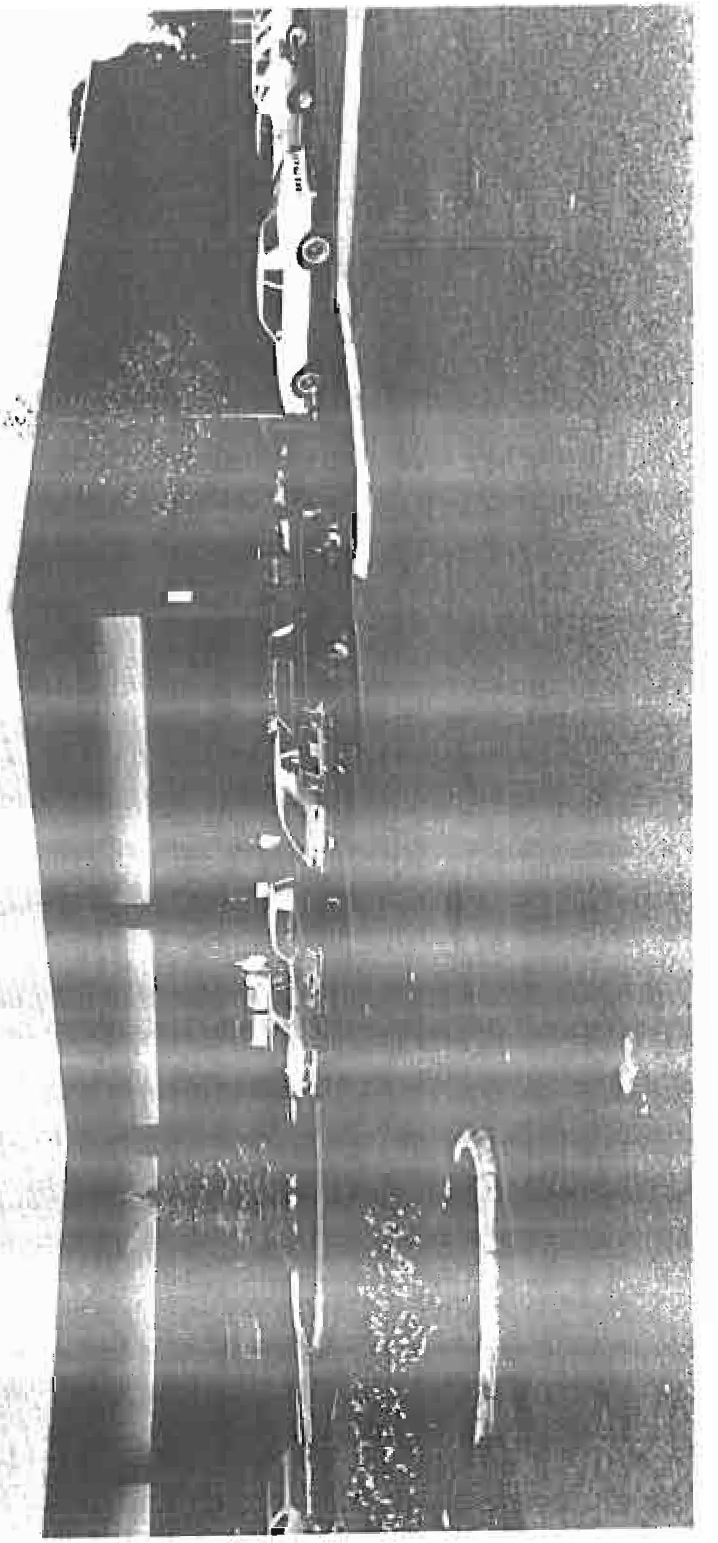

FIGURE B.5. Retail - Strip Store

FIGURE B.6. Multifamily Housing

FIGURE B.7. Hotel/Motel

B.8 WAREHOUSE

The warehouse evaluated was built in Tualatin, Oregon, in 1975 (Figure B.8). It has a gross area of 40,752 ft^2 on one floor, with 38,640 ft^2 of warehousing and 2112 ft^2 of conditioned office space. The building is constructed of precast concrete tilt-up walls for the warehousing area (24-foot height), and wood-frame/cedar-siding construction for the office spaces (12-foot height). There are 9 loading bays on the rear of the building. Only the office space has windows of any significance. Total glazing is less than 3% on all exposures.

The warehouse operates 8 a.m. to 5 p.m. six days per week, whereas the office maintains a typical 5-day office schedule with minimal Saturday operation. There are 46 occupants.

B.9 PUBLIC ASSEMBLY

The assembly building evaluated in this project was a community center/church, whose basic floor plan is being replicated at various sites across the country (Figure B.9). The center is a low-cost one-floor building of 14,150 ft^2. About 15% of the area is chapel, 23% cultural center, and 62% offices and meeting rooms. The building is wood-framed with a trussed roof, and the floor-to-roof height is 15 feet (average) in the office and meeting rooms, and 25 feet in the chapel and cultural center. The building has between 25% and 30% glass on all sides.

The building is designed for 614 occupants and has a schedule characterized by heavy use on Sundays (daytime), Saturday and weekday evenings for the church and cultural center. The offices observe a long office schedule 5 days per week.

B.10 SCHOOL

The school building evaluated is a junior-high school, built in Pendleton, Oregon, in 1982 (Figure B.10). As constructed, it is a modern two-story solar building, constructed in a boomerang shape, with the convex side to the

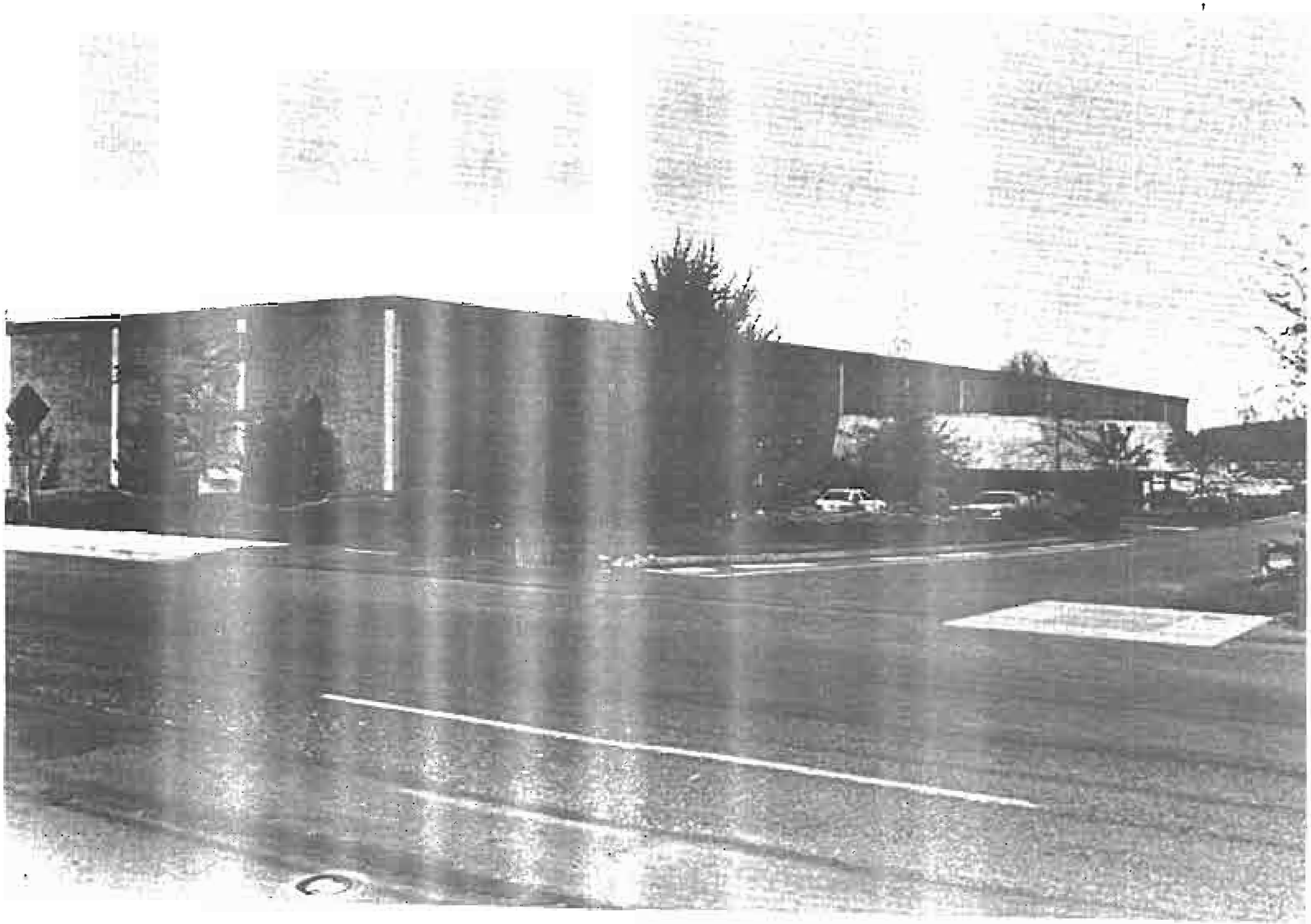

FIGURE B.8. Warehouse

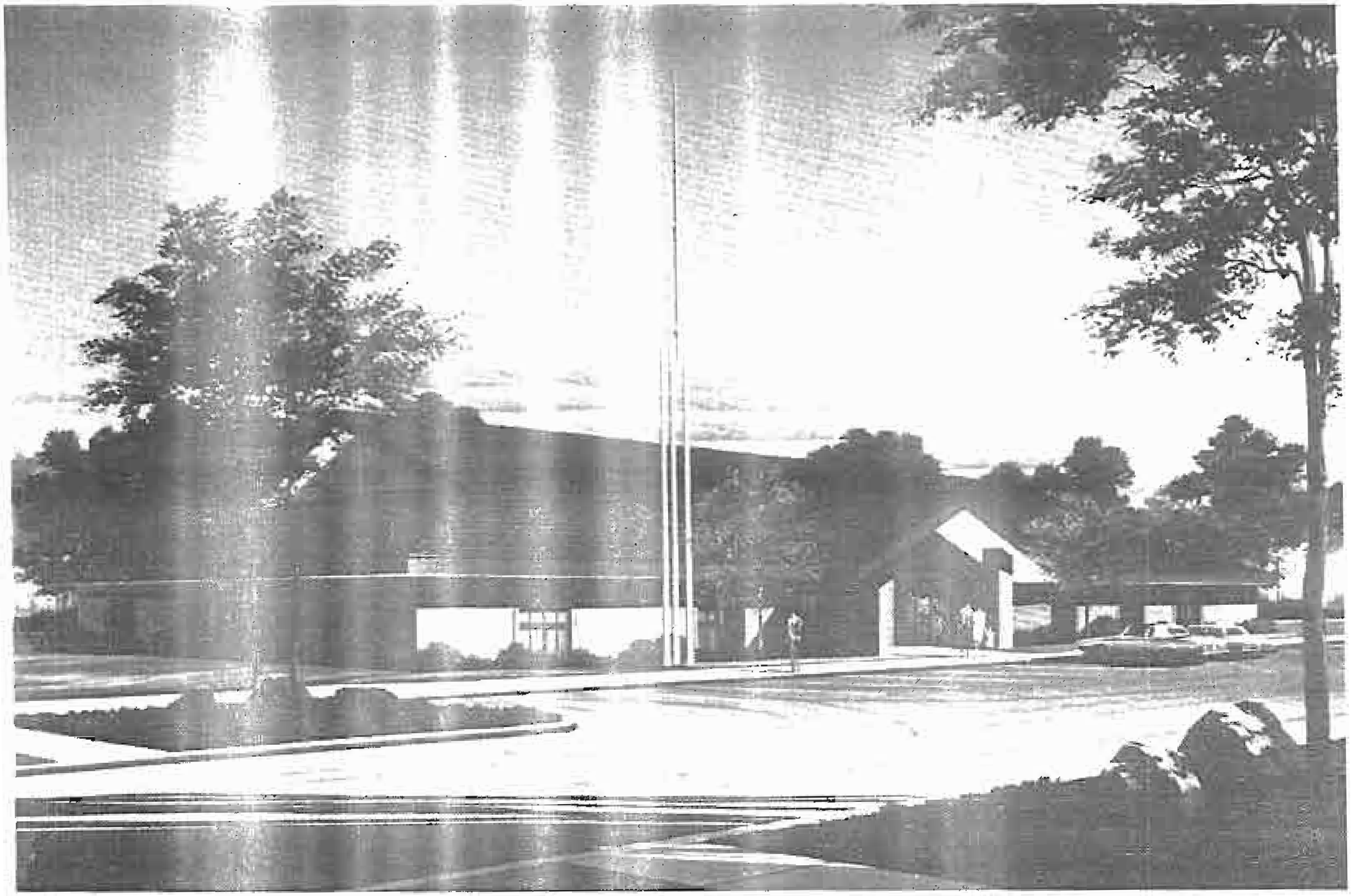

FIGURE B.9. Public Assembly Building

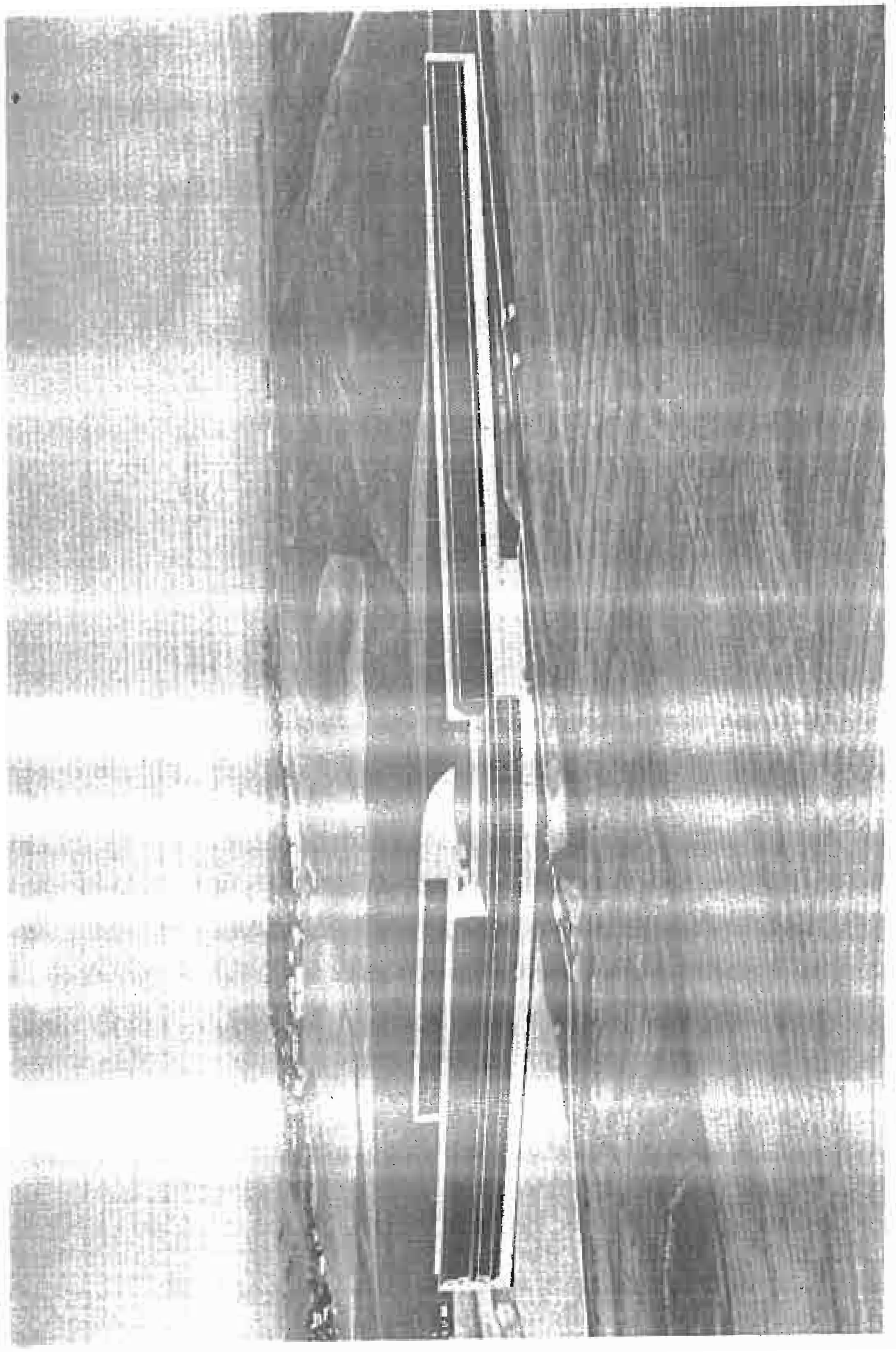

FIGURE B.10. Public School

south. It has an active hot-air solar system on the south side of the building, and roof monitors for illuminating the classroom areas. For this project, the building was modeled without the active solar system and with a flat roof over the building. Skylights were modeled instead of the roof monitors. Construction is metal siding over wood framing--typical residential-type construction. Floor height is 9 1/2 feet for classrooms and offices, 14 feet for the gymnasium, and 20 feet for the student center.

The building has 123,666 ft^2, apportioned to classrooms (46%), gymnasium and student center (46%), offices (5%), and food service (3%). Occupancy is 2161 people over 9 winter months on a typical school schedule.

B.11 REFERENCES

Pacific Northwest Laboratory. 1983. Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. PNL-4870, 4 Volumes, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX C

INDOOR AIR QUALITY MONITORING

APPENDIX C

INDOOR AIR QUALITY MONITORING

This appendix describes the indoor air quality monitoring undertaken to support the indoor air quality modeling effort. Five structures were monitored for indoor air quality and air exchange rate: a single-level small office building; two sections of a seven-story office building; the first floor of a small, energy-efficient, two-story office building; a machine/metal/wood-shop; and a warehouse. All buildings are located in the Pacific Northwest region and were monitored between February 3, 1983, and March 29, 1983. The instrumentation, the sampling protocol, structure description, and a summary of the monitoring results for each building are given in the following sections.

C.1 INSTRUMENTATION

Indoor concentrations of radon, oxides of nitrogen, formaldehyde, carbon monoxide, total hydrocarbons and particulate matter were measured in each building. Outdoor concentrations of formaldehyde, oxides of nitrogen, carbon monoxide, total hydrocarbons and total suspended particulates were also measured. In addition, indoor and outdoor temperature, windspeed and relative humidity were measured. Air exchange rate was also measured using a sulfur hexafluoride gas tracer technique. In the two-story office building, the HVAC airflow was measured. The concentrations measured and the instruments used are described in the following sections.

C.1.1 Radon

Radon (^{222}Rn) was measured using an Eberline Instruments RGM-1 radon gas monitor. The RGM-1 is a complete, portable system for continuous measurement of radon gas.

Before the monitoring, the Eberline RGM-1 was calibrated in a special calibration chamber in Grand Junction, Colorado. In this chamber, a known concentration of radon gas formed from radium-226 decay was passed through the instrument and the counts recorded by the RGM-1. Background counts (from dark current and other sources causing the instrument to record a count pulse) were subtraced and a relationship between counts and radon concentration in pico-Curies per liter (pCi/ℓ) of air was established.

The basic method for detecting the gas is as follows: air, filtered to remove aerosols at a flow rate of about 1 liter/min, passes through an Eberline Scintillation Detector that consists of a 1.4 ℓ (liter) scintillation cell coated on the inside with zinc sulfide, and a 5-inch diameter photomultiplier tube in a light-tight housing. The radon detector responds because of plate-out of radon progeny on the inside of the cell walls; the detector measures the alpha emission of the radon gas as it moves through into its progeny. By integrating continuously with hourly printouts, the integrated count is proportionated to average ^{222}Rn concentration in pCi/ℓ. The total counts accumulated over a preset time interval (2, 20, or 60 minutes) are recorded automatically by a printer.

The system is capable of measuring concentrations of ^{222}Rn as low as 0.01 pCi/ℓ(± 0.01 pCi/ℓ) and as high as several hundred pCi/ℓ. The instrument is designed to operate continuously for several days without attendance.

C.1.2 Oxides of Nitrogen

Indoor concentrations of oxides of nitrogen (NO, NO_2, NO_x) were measured using a Monitor Labs 8840 Nitrogen Oxides Analyzer. The analyzer can operate continuously without attendance. This instrument is a real-time detector using a dual channel chemiluminescent (reaction chamber) measurement method. The entering air is divided into two paths, one airstream going directly to a reaction chamber and one going through the molycon converter. The converter selectively converts NO_2 to NO without interference from ammonia. Both paths reach the reaction chambers simultaneously where in separate chambers NO and NO_x are detected by their chemiluminescent reactions with ozone (generated within the instrument from room air). The difference between the two readings (NO and NO_x) is NO_2. The instrument can detect NO_x and NO concentrations as low as 0.5 parts per billion (ppb) (± 0.10 ppb). The instrument simultaneously recorded NO and NO_x concentrations on a strip-chart recorder. Calibration was performed using standard NO_2 calibration gas.

Outdoor concentrations of oxides of nitrogen were measured using a PNL-developed instrument similar to the Monitor Labs 8840. The measurement principles, operation and detection limit also are identical to the 8840 analyzer.

C.1.3 Formaldehyde

Formaldehyde was measured inside and outside using a PF-1 formaldehyde passive integrated monitor available from Air Quality Research Inc. The monitor consists of 1-in. diameter by 4-in. long glass tube capped at one end and filtered at the other end (inside). The glass fiber filter is coated with a nontoxic chemical that will react and absorb formaldehyde in the air. The monitor is hung from the ceiling in a room or outside, uncapped and allowed to absorb formaldehyde for 4 days or more. The monitor is sent back to the supplier for analysis, which gives the formaldehyde concentration for the time period in which the monitor was left in the room. These monitors are capable of measuring formaldehyde concentrations as low as 0.01 parts per million (ppm) (± 0.0015 ppm).

C.1.4 Carbon Monoxide

Carbon monoxide (CO) was measured with two instruments. The first instrument, used for both inside and outside analysis, was a Miran Model 80 high-performance, single-beam infrared continuous analyzer manufactured by Wilkes Scientific Corporation. The instrument was programmed to scan the infrared absorbance wavelength of CO and to automatically print out the absorbance every 34 minutes on a self-contained tape. The minimum detectable concentration for CO is 0.2 ppm (± 0.01 ppm). From the amount of absorbance, the actual concentration of CO was determined from a calibration curve. The unit was calibrated using standard CO calibration gas supplied by Scott Marin Co. and contained in gas bags and run through the instrument. The system was zeroed periodically with pure N_2.

Carbon monoxide inside and outside was also measured using two hand-held MINICO®(a) detectors manufactured by Mine Safety Appliance Co. Air is passively introduced by natural diffusion through a Teflon®(b) membrane at the

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(a) MINICO® is a trademark of Mine Safety Appliance Company.
(b) Teflon® is a trademark of Dow Chemical.

bottom of the opening in the instrument face to the surface of a sealed sensor unit containing a sulfuric acid electrolyte. The cell electro-oxidizes CO to carbon dioxide (CO_2) in proportion to the partial pressure of CO in the sample area. The resulting electrochemical signal is amplified and temperature-compensated to drive a digital readout display that must be periodically read. The instrument is capable of detecting CO as low as 1 ppm (± 0.5 ppm). The instruments were calibrated using standard Scott Marin calibration gas passed before the surface of the sensor.

C.1.5 Particulate Matter

Particulate matter was measured using a GCA Corporation real-time aerosol monitor, Model RAM-1. The RAM-1 is a battery-operated unit that pulls a sample of room air at 2 ℓpm through the sensing element. It uses a pulsed light-emitting diode in combination with a silicon detector to sense the light scattered over a forward angle of 45° to 90° by the particles transversing the sensing volume. The output is continuous (either digital display or analog) and is linearly related to the aerosol particle concentration. The instrument measures particles less than 0.1 to 20 micrometers in diameter. The measurement range is 0.0001 to 200 mg/m^3 (milligram per cubic meter) with ±0.1% full-scale precision. Calibration is provided by an internal reference scatter based on a representative respirable test dust. Calibration was performed weekly.

C.1.6 Tracer Gas Detection

The tracer gas used to determine the air exchange rate was sulfur hexafluoride (SF_6). The gas was released into the building using either a sampling syringe or through a small hole in a gas bag filled with SF_6. The SF_6 gas concentration was measured every 5 to 10 minutes for several hours using a portable gas chromatograph manufactured by Science Systems and Software. The chromatograph was designed specifically to measure low concentrations of SF_6 using an electron capture detector. The decrease of SF_6 concentration with time was a measure of the exchange of air between the inside and outside air. The air exchange rate was determined by plotting the SF_6 versus time and recorded as air changes per hour (ACH). Periodic chromatograph response to known SF_6 concentrations was performed using bottled calibration gas supplied by Scott Marin.

C.2 MEASUREMENT PROTOCOL

The discussion on measurement protocol is broken down into three sections: 1) indoor air quality, 2) outdoor air quality, and 3) air exchange. The protocol discussed here is the general method followed in the entire commercial building study, not the specific method used in each building monitoring study. The specific protocol is discussed in the results of the monitoring for each building in Section C.4.

Each building to be monitored was surveyed to establish the instruments' sampling location. The instruments had to be somewhat isolated for inside measurements because of instrument noise. Sampling lines and some of the quiet sampling instruments were placed in a sampling area that was considered to be open space (e.g., not in an individual office), away from walls, and representative of average conditions of air quality in that building (e.g., samples were not taken over a smoker's desk).

Instruments for outdoor measurements were placed in areas clear of pedestrian traffic and in areas considered representative of average outdoor conditions (e.g., not next to an exhaust fan from the building). In some cases outdoor measurements were taken by locating instruments indoors and running sampling lines through windows or doors. Indoor and outdoor air quality was generally measured simultaneously.

C.2.1 Indoor Air Quality

Indoor air quality was measured for approximately 3 days in each building or building section. For active (mechanical) instruments that could run continuously with little attendance (radon, NO_x, particulate matter), the analysis in some of the buildings was performed continuously for the 3 days. For instruments that could not be left unattended or that did not give recorded output, analysis was performed during 3 to 4 periods during a 24-hour period. One of the measurement periods was during nonworking hours of a working day, and an attempt was made to monitor during a weekend (nonworking) day in each building.

An attempt was also made to measure indoor (and outdoor) air quality during both calm and windy days or during calm and windy periods during any given day. This was not always possible given the time constraints for monitoring in a specific building or area.

As part of the indoor monitoring, the general indoor conditions or activity during monitoring were noted. This observation included noting number of people occupying the building and number of smokers in the building, plus activity (such as painting, vacuuming, cleaning, grinding, etc.) nearby the sampling area or in the building.

C.2.2 Outdoor Air Quality

Outdoor air quality was measured simultaneously with the indoor air quality for most of the measurement periods, except when instruments were not operating properly or when instruments from the indoor monitoring were used for outdoor monitoring after indoor monitoring was completed. In some buildings, outdoor air quality could not be continuously monitored because instruments could not be left outside or sampling lines could not be run from inside to the outside for 24 continuous hours. However, outdoor quality was measured for as long as 6 to 8 continuous hours during a sampling day (see specific building monitoring results, Section C.4).

During outdoor sampling periods, activities were noted, such as the passage of heavy traffic in front of the building (especially buses and diesel vehicles). General atmospheric conditions were also noted (i.e., fog, rain, smoke, etc.).

C.2.3 Air Exchange Rate

The air exchange rate was measured on most monitoring days using sulfur hexafluoride (SF_6) tracer gas and gas chromatography analysis. A small amount of SF_6 gas was released into the building either at several locations within the building or into the fresh-air intake of the heating, ventilation and air conditioning (HVAC) system. The amount of SF_6 released depended upon the estimated volume of the building and the estimated percent fresh air intake (for HVAC systems). Depending upon the analysis time (1 to 5 hours), which depended upon the air exchange rate, at least two air exchange rate measurements were made during a monitoring day. For some buildings, the air exchange rate was measured,while the HVAC system was off and the building was unoccupied, and therefore (theoretically) air exchange in the building would be from natural infiltration (from cracks and openings in the structure).

C.3 BUILDING DESCRIPTION

In this section each monitored building is described, including approximate age, construction type, size and other important characteristics that influence air exchange and indoor air quality.

C.3.1 Building #1

Building #1 is located in the north end of Richland, Washington, in an area consisting predominantly of offices and light industry. It is a single-story office building built in 1978 and constructed of a steel shell with brick walls and slab-on-grade. The building is about 16,000 ft^2 and contains primarily small (15 ft x 10 ft) enclosed offices (with doors) and an all-electric kitchen/lunchroom. The building is heated/cooled by electric resistance heat pumps mounted on the roof. The central HVAC system is roof-mounted and run continuously. Automatic air dampers control fresh air intake and are adjusted continuously as a function of air temperature. The fresh air intake for the HVAC system is filtered through fiberglass filters.

The building is occupied by about 100 workers. Less than 5% of the workers were smokers during the measurement period. A twin double door entrance to the building is located at the southwest corner. Aside from 2 dry copiers (and the occupants themselves), the building has no other major sources of pollutants.

C.3.2 Building #2

Building #2 is in downtown Richland, Washington, near two of the busiest streets. The building is constructed of a steel shell with marble and cement walls. The main part of the building is a seven-story structure built about 1967. This part of the building contains primarily offices (mostly small offices with a few open areas). The other section of the building is a two-story side addition built about 1969 and contains an auditorium, conference rooms, a cafeteria and offices. The cafeteria contains natural gas ovens and stoves. A basement runs under the entire building and houses some offices plus the mechanical equipment and heat plant. The building is heated by a natural gas-fired central boiler and is cooled by electric roof-mounted chillers. The central HVAC systems are roof-mounted (one system on each section of the building) with air intakes at roof level. The fresh air intakes for both systems are filtered through a rolling filter, and dampers on the intakes are manually adjusted depending upon the outside temperature and the season. The HVAC system in the 7-story section is turned off at 6 p.m. on weekdays and all day on weekends and holidays. It is turned on at 5 a.m. Monday through Friday. The HVAC system for the other section of the building runs continuously.

The floor area of the 7-story section is about 300,000 ft^2 and the floor area of the other section is about 69,000 ft^2. About 1300 people occupy the building; approximately 15% were estimated to be smokers during the monitoring period.

C.3.3 Building #3

Building #3, an accounting office/shop, is located atop a hill in the north part of Vancouver, Washington, about one half mile from the Interstate 5 freeway in a rural/residential area. The office was built about 1974 and was built to be "energy-efficient" with tight construction and few windows, none of which open. The building is steel, concrete and wood construction and is two stories with an underground basement. The basement contains change rooms, restrooms, electrical equipment and storage, plus one small audio/visual workroom. The first and second floors are office areas and are central open bays with individual offices (with doors) around the perimeter. A conference room is located upstairs and a copying/computer room is located on the first floor, along with a small kitchen.

The building is electrically heated and cooled through a central HVAC system (one system for the basement and first floor, one system for the second floor) with roof-mounted air intakes. Both HVAC systems are shut down at 5 p.m. on weekdays and are off on weekends and holidays. They are turned on at

6 a.m. each weekday; bathroom vents (2) remain on continuously, however. Fresh air intakes are adjusted (dampered) automatically according to outside temperature demands. There is no filtration of the HVAC system air.

On the first floor, the main office is about 1300 ft^2, with an adjacent office of about 500 ft^2. These 2 offices are separated by a fire wall and 2 self-closing doors. The upstairs office is about 1800 ft^2 and the basement is about 1300 ft^2. The first floor offices have 16 occupants, 6 of whom were smokers during the measurement period. The upstairs office has 14 occupants, including 4 who were smokers during the measurement period.

C.3.4 Shop Area of Building #3

The shop area is located within the same building shell as the Building #3. The shop is north of the accounting office and is separated from it by a fire wall. The shop area is built slab-on-grade and is on one level. It is about 20,000 ft^2 with 30-foot-high ceilings. The shop area is divided into several segments by walls or curtains but is primarily an open area. The only areas set apart from the main shop are an enclosed paint room, which has its own exhaust ventilation system, and an enclosed wood shop, which also has its own exhaust system (for sawdust). The main area does not have any central HVAC system and is heated by overhead electric resistance heaters. Ventilation is primarily through large 12' x 25' bay doors located on 2 of the 4 walls of the buildings. These doors are open at various times for vehicle access to allow transport of material or just to provide natural ventilation on warm days.

Activities in the shop include vehicle and lift truck movement (gas and diesel), metal grinding, welding, machining, sawing, drilling, metal-plating, etc. The welding and metal-plating area is segmented from the rest of the shop by transparent full-length curtains and sound boards. Each welding station and metal plating area is equipped with area exhaust ducts connected to a central overhead electrostatic precipitator (ESP) that is used to filter out fumes and particles. The return air from the ESP is into the main shop area. Limited welding activities (with area exhaust ventilation) also occur in other parts of the building.

About 30 to 40 people work in the shop with activity beginning at 8 a.m. and ending at 4:30 p.m. All access doors from the shop to the shop office and accounting office are self-closing and normally are closed during the day. Activity ceases for one half hour during lunch, 12:00 to 12:30 p.m., and for 15 minutes twice a day, during morning and afternoon breaks.

C.3.5 Building #4

Building #4 is a warehouse located north and down a hill from Building #3. It is a single-story slab-on-grade, primarily open structure constructed of steel, concrete and aluminum. It is approximately 100,000 ft^2 with several large 12 x 25 foot bay doors at either end of the building and along the sides. Attached to the warehouse is an office area that is separated by a fire wall. The office area is about 1500 ft^2 and is serviced by a central HVAC system operated in the same manner as that in Building #3. The warehouse is divided into 6 segments by floor-to-ceiling walls. The two largest segments are about 40,000 ft^2 each, and access is through a 12-foot wide opening between the walls. Other segments include a meeting/lunch room (about 500 ft^2), an all-electric kitchen/rest room (3000 ft^2), an electrical equipment storage room (10,000 ft^2), and the receiving office (800 ft^2). The segments are closed off from the main warehouse by large fire doors or fire walls.

During a working day, the large bay doors at each end of the building are normally open, and one or two receiving doors on the west side of the building are opened periodically to receive or to move shipments. Activities include moving materials by gas, diesel and electric lift trucks, unpacking equipment, and some machining of equipment. The warehouse contains about 15 people plus those in the main office area. The warehouse has no central HVAC system and is heated by overhead forced air electric heaters that maintain a constant temperature of about 55°F during the heating season. Cooling is provided by several roof-mounted vents, which can be opened to let out the heat. Activity starts at 8 a.m. and ceases at 4:30 p.m. each day.

C.4 AIR QUALITY MEASUREMENTS

This section discusses the results of the air quality measurements in each of the five locations.

C.4.1 Air Quality Measurements in Building #1

The air quality inside and outside of Building #1 was measured from February 3 to 5, 1983. The monitoring location for the indoor air quality was the library, a large room (25 x 25 feet) situated approximately in the middle of the building. The room was occupied during working hours by two nonsmokers. This room has three doors, two of which were open during the sampling periods.

The sampling of outdoor air was conducted at the entrance to the building near the parking lot. A sampling line for the NO_x was placed 15 feet above the ground. Sampling for particulate matter and total hydrocarbons was at ground level. The formaldehyde sampler was placed at about 7 feet above ground. Windspeed and temperature were measured from a meteorological tower atop the building about 35 feet above ground level.

Indoor and outdoor measurements were taken 3 times on Wednesday (2/3), and Thursday (2/4), and 3 times on Saturday (2/5), for about an hour each time. Temperature and windspeed were recorded hourly. The only continuous monitoring performed over these 3 days was for indoor radon. Carbon monoxide was not monitored (inside or outside) for this building because of instrument malfunction. Relative humidity also was not measured.

The time average measurements for a work day (8 a.m.-4 p.m.) in Building #1 are summarized in Table C.1. Mean concentrations and standard deviations of the measurements from the table are given for the workday (8 a.m.-4 p.m.) for Thursday (2/3) and Friday (2/4) and for the same hours (8 a.m.-4 p.m.) for a non-work day (Saturday, 2/5). The concentration of indoor and outdoor formaldehyde is a 24-hour (daily) average concentration for 5 continuous days (2/3-2/7). Table C.1 also gives workday average temperature and windspeed.

C.4.2 Air Quality Measurements in Building #2

Two locations within Building #2 were monitored. The first location was on the sixth floor in the library. The second location was on the ground floor in an office area in the newer segment of the building.

Sixth Floor Library

The library on the sixth floor is an area of about 1100 ft^2, occupied by one nonsmoker during working hours. The sampling lines for radon, NO_x and CO

TABLE C.1. Summary of Measurements in Library of Building #1

Day/Date	Parameter	Time Average (0800-1600 hours) Inside	Outside
Thursday, 2/3	Air Exchange Rate[(a)]	1.1 ACH	--
	Temperature	68°F	35°F
	Windspeed[(b)]	--	2 m/s
	Radon[(c)]	0.35 ± 0.08 pCi/ℓ	--
	Particulate Matter[(d)]	42 ± 10 μg/m^3	19 ± 7 μg/m^3
	NO_x[(e)]	23 ± 10 ppb	15 ± 11 ppb
Friday, 2/4	Air Exchange Rate	0.67 ACH	--
	Temperature	68°F	30°F
	Windspeed	--	0.5 m/s
	Radon	0.38 ± 0.14 pCi/ℓ	--
	Particulate Matter	21 ± 4 μg/m^3	37 ± 18 μg/m^3 (fog)
	NO_x	10 ± 2 ppb	6 ± 3 ppb
Saturday, 2/5	Air Exchange Rate	0.89 ACH	--
	Temperature	67°F	29°F
	Windspeed	--	1 m/s
	Radon	0.25 ± 0.09 pCi/ℓ	--
	Particulate Matter	<10 μg/m^3	57 ± 15 μg/m^3 (fog)
	NO_x	7 ± 2 ppb	9 ± 2 ppb
2/3 - 2/7	Formaldehyde[(f)]	0.005 ppm	0.007 ppm

(a) Values are in air changes per hour (ACH), ±15%.
(b) Values are in meters per second (m/s).
(c) Values are in picoCuries per liter (pCi/ℓ) (10^{-12} Curies/liter).
(d) Values are in micrograms per cubic meter (μg/m^3) (10^{-6} g/m^3).
(e) Oxides of nitrogen: NO + NO_2; values are in parts per billion (ppb).
(f) Values are in parts per million (ppm), ±15%.

were suspended about 7 feet above the floor in a central location. A formaldehyde detector tube was also located 7 feet above the floor. The monitor of particulate matter was located about 6 feet above the floor on a shelf. No measurements for total hydrocarbons were taken at this location.

Sampling was performed on February 18, 19, and 22. Monday, February 21, was a holiday. Continuous inside monitoring was performed for radon and NO_x; all other measurements were periodic (except for formaldehyde, which is an integrated sample). Outside air was sampled only periodically due to the difficulty of opening locked windows and running sampling lines. The outside formaldehyde detector was placed about 6 feet above the ground outside the first-floor north entrance to the building. Windspeed and temperature were measured a few times using the outside hand-held instrument from the roof of the building, one story above the sixth floor.

Table C.2 shows the indoor and outdoors monitoring record for this location. Table C.3 gives the time average of the monitoring data for a work day (0800-1600 hours), including the air exchange rate measurements.

Ground Floor Office - Building #2

A ground floor office in Building #2 was monitored on February 25 and 26 (Friday and Saturday) and March 2 and 3 (Wednesday and Thursday). The office area is one large (36 x 15 feet) open office with two offices adjacent, one 16 x 27, the other 9 x 27 feet. Total area is about 1200 ft^2. Instruments were located in an adjacent storage area connected by a door normally closed to the office area. A central area of the large office area was chosen for monitoring. This area contained two nonsmokers and one smoker. The smoker was in one adjacent office; the door between the sampling area and this office was open most of the time. The other adjacent office was occupied by a nonsmoker; the door to this office was normally closed. The main large office area also contained a copy machine in one corner.

Sampling lines for radon, CO and NO_x were suspended about 7.5 feet above the floor in the middle of the large office. The detector for formaldehyde was also located about 7.5 feet above the floor. Sampling for total hydrocarbons was done from a shelf about 6 feet above the floor near one wall of the large office area. Particulate matter sampling was done from an empty desk located near the entrance to the large office area.

Outdoor measurements were performed through a window in the storage area (where the instruments were located). As with the 6th floor office, outdoor sampling was done only occasionally because of the difficulty of sampling through secured (locked) windows. In addition, instrument breakdown prevented

TABLE C.2. Monitoring Record for the Sixth Floor Library of Building #2

Date	Time	CO_{in} ppm	CO_{out} ppm	NO_x in ppm	NO_x out ppm	Radon pCi/ℓ	TSP_{in} µg/m³	TSP_{out} µg/m³	$Temp_{in}$ °F	$Temp_{out}$ °F	Wind Speed m/s	Air Exchange ACH	Notes
2/18	0800			0.040		0.08	15		68		1		Building full/person in library.
Friday	0900	1.9		0.024		0.17	25						Rain overcast, calm.
	1000			0.024		0.14		<10					
	1100		3.7	0.024		0.07		<10					
	1200			0.022		0.09							
	1300			0.022		0.17						4	Cigar smoker in room. HVAC-on.
	1400			0.020		0.04	300		69	44		4	
	1500	<1		0.020		0.11	<10					4	
	1600			0.018		0.01							
	1700			0.020		0.08							
	1800			0.018		0.13							
	1900			0.016		0.01							
	2000			0.016		0.10			68	40-45	2		HVAC-off, calm, cloudy.
	2100	3.2		0.016		0.10							
	2200			0.016		0.06							
	2300			0.016		0.13	<10						
	2400			0.016		0.02	<10						
2/19	0100			0.014		0.01							
Saturday	0200			0.014		0.11							
	0300			0.012		0.13							
	0400			0.010		0.13							
	0500			0.010		0.18							
	0600			0.010		0.12							
	0700			0.014		0.05							
	0800			0.016		0.08							
	0900			0.014		0.07							
	1000			0.012		0.08	<10		68	45	6	0.3	6th floor empty, lights and fans
	1100	1.2		0.010		0.16	<10					0.3	off, doors to outer offices
	1200			0.010		0.12						0.3	closed. Clear, slight wind.
	1300			0.010		0.12						0.3	HVAC-off.
	1400			0.010		0.09						0.3	
	1500			0.011		0.09						0.3	
	1600			0.011		0.06							
	1700			0.012		0.15							
	1800			0.012		0.08							
	1900			0.013		0.01							
	2000			0.013		0.09							
	2100			0.012		0.02	<10		70		2		Calm. HVAC-off, building empty.
	2200	3.4		0.012		0.03	<10						
	2300			0.010		0.09							
	2400			0.009		0.15							
2/22	0100			0.008		0.14							
Tuesday	0200			0.008		0.24							
	0300			0.006		0.19							
	0400			0.005		0.16							
	0500			0.005		0.23							
	0600			0.005		0.26							
	0700			0.010		0.18							
	0800			0.120		0.17	40		70		1		Smoker in library for short time.
	0900	1.0		0.010		0.22	30						Foggy, still.
	1000					0.16							
	1100					0.24				50			
	1200					0.07							
	1300					0.12							
	1400			0.020		0.16	15		70				Building full.
	1500			0.018		0.05	15						
	1600	<1.0		0.018		0.22							
	1700					0.17							
	1800					0.02							
	1900					0.08							
	2000					0.12							
	2100					0.03							
	2200			0.017		0.14	<10		70	48	<1		Calm, cloudy. HVAC-off.
	2300	2.2		0.017		0.17	<10						

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ppm = parts per million
pCi/ℓ = picoCuries per liter
µg/m³ = micrograms per cubic meter
m/s = meters per second
ACH = air changes per hour

TABLE C.3. Summary of Measurements for Sixth Floor Library of Building #2

Day/Date	Parameter	Time Average (0800-1600 hours)	
		Inside	Outside
Friday, 2/18	Air Exchange Rate(a)	4 ACH	--
	Temperature	68°F	44°F
	Windspeed(b)	--	--
	Radon(c)	0.10 ± 0.06 pCi/ℓ	--
	Particulate Matter(d)	15 ± 7 $\mu g/m^3$	<10 $\mu g/m^3$
	NO_x(e)	24 ± 6 ppb	--
	CO	1.5 ± 0.6 ppm	3.7 ppm
Saturday, 2/19 HVAC-off	Air Exchange Rate	0.3 ACH	--
	Temperature	69°F	45°F
	Windspeed	--	5 m/s
	Radon	0.10 ± 0.08 pCi/ℓ	--
	Particulate Matter	<10 $\mu g/m^3$	--
	NO_x	16 ± 2 ppb	--
	CO	1.2 ppm	--
Tuesday, 2/22	Air Exchange Rate	--	--
	Temperature	70°F	50°F
	Windspeed	--	--
	Radon	0.16 ± 0.07 pCi/ℓ	--
	Particulate Matter	25 ± 12 $\mu g/m^3$	--
	NO_x	55 ± 51 ppb	--
	CO	1.4 ± 7 ppm	--
2/18 - 2/22	Formaldehyde(f)	0.011 ppm	0.012 ppm

(a) Values are in air changes per hour (ACH) ±15%.
(b) Values are in meters per second (m/s).
(c) Values are in picoCuries per liter (pCi/ℓ) (10^{-12} Curies/liter).
(d) Values are in micrograms per cubic meter ($\mu g/m^3$) (10^{-6} g/m^3).
(e) Oxides of nitrogen: NO + NO_2; values are in parts per billion (ppb).
(f) Values are in parts per million (ppm), ±15%.

sampling NO_x outdoors for most of the sampling period. Windspeed and temperature were measured outside the north entrance to the building a good distance from the building. The outdoor formaldehyde detector was hung about 6 feet above the ground at the north entrance to the building.

Table C.4 gives the indoor and outdoor monitoring record for this location. Table C.5 gives the time average of the monitoring data for a work-day hours (0800-1600), including the air exchange rate measurements.

TABLE C.4. Monitoring Record for the Ground Floor Office of Building #2

Date	Time	CO_{in} ppm	CO_{out} ppm	NO_x in ppm	NO_x out ppm	HC_{in} ppm	HC_{out} ppm	Radon pCi/l	TSP_{in} µg/m³	TSP_{out} µg/m³	$Temp_{in}$ °F	$Temp_{out}$ °F	Wind Speed m/s	Air Exchange ACH	Notes
2/25 Friday	0800	1.2		0.018				0.18	45	<5	68	44	<1		Clear.
	0900	<1	2.8	0.044		<1		0.16	90	<5					
	0100		<1	0.030			<1	0.01						1.7	Air exchange value is average for several ground floor locations. No smoker in office. Cloudy, overcast.
	1100			0.025				0.11						1.7	
	1200			0.030				0.06						1.7	
	1300	2.	5	0.032				0.11	43		58	55			
	1400	3.7	3.7	0.014	<1			0.03	18	<5					
	1500		3.3	0.025		<1		0.02		<5			1		
	1600			0.022				0.07							
	1700			0.018				0.09							
	1800			0.014				0.09							
	1900			0.013				0.12	22		54				Janitor doing cleanup - otherwise floor and office empty.
	2000			0.017				0.04	30						
	2100			0.010				0.01							
	2200			0.008				0.02							
	2300			0.008				0.06							
	2400			0.006				0.05							
2/26 Saturday	0100			0.007				0.13							
	0200			0.009				0.02							
	0300			0.008				0.01							
	0400			0.007				0.01							
	0500			0.008				0.06							
	0600			0.010				0.01							
	0700			0.010				0.03							
	0800			0.010				0.06							
	0900			0.012				0.03							
	1000			0.010				0.01							
	1100			0.008				0.01	<10		58	58	1	2.6	HVAC-on, Calm.
	1200			0.008	<1			0.05	<10					2.6	
	1300			0.008				0.01							
	1400			0.008				0.04							
	1500			0.008				0.01							
	1600			0.008				0.01							
	1700			0.008				0.01	<10		63	52	1		HVAC-on, office/building empty, partly cloudy-calm.
	1800			0.025	<1			0.01	<10						
	1900			0.042				0.01							
	2000			0.060				0.03							
	2100			--				0.12							
	2200			--				0.09							
	2300			0.042				0.12							
	2400			0.085				0.08							
3/2 Wednesday	0100			--				0.08							
	0200			--				0.03							
	0300			--				0.07							
	0400			--				0.06							
	0500			--				0.12							
	0600			--				0.08							
	0700			--				0.13							
	0800			--				0.06							3 people in office. Conference room (nearby) in use. 1 smoker at desk 20 feet away. 2 smokers entered room. Calm, clear. HVAC-on TSP level in instrument room is <5 µg/m³.
	0900			--				0.16							
	1000	3		--				0.10	100						
	1100	2	2	0.013				0.01	385			52	2	2.5	
	1200			0.018	<1			0.01						2.5	
	1300			0.012				0.08						2.5	
	1400			0.021				0.05							
	1500			0.020				0.08							
	1600			0.022				0.06	30						
	1700	1		0.027				0.06	<10			53	2		Office empty. Clear, calm.
	1800	2		0.023				0.03	<10						
	1900			0.022				--							
	2000			0.012				--							
	2100			0.010				--							
	2200			0.012				--							
	2300			0.009				--							
	2400			0.011				--							
3/3 Thursday	0100			0.010				--							
	0200			0.022				--							
	0300			0.009				--							
	0400			0.008				--							
	0500			0.008				--							
	0600			0.015				--							
	0700			0.052				--							
	0800			0.112				--							HVAC-on. Clear, calm. 1 smoker at desk 20 away. 2 smokers in office temporarily.
	0900	3		0.069				0.08	110		66	50	2		
	1000	3		0.028	<1			0.01	440						
	1100			0.023	<1			0.01							
	1200			0.022				0.14							
	1300			0.012				0.09							
	1400			0.016				0.05							
	1500			0.022				0.01							
	1500			0.030				0.08	150						1 person in office - nonsmoker. Copy machine in periodic use. HVAC-on.
	1700			0.024	<1			0.07	65			60			

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ppm = parts per million
pCi/l = picoCuries per liter
µg/m³ = micrograms per cubic meter
m/s = meters per second
ACH = air changes per hour

TABLE C.5. Summary of Measurements in Ground Floor Office of Building #2

Day/Date	Parameter	Time Average (0800-1600 hours) Inside	Outside
Friday, 2/25	Air Exchange Rate (a)	1.7 ACH	--
	Temperature	63°F	50°F
	Windspeed (b)	--	--
	Radon (c)	0.08 ± 0.06 pCi/ℓ	--
	Particulate Matter (d)	49 ± 30 $\mu g/m^3$	<5 $\mu g/m^3$
	NO$_x$ (e)	25 ± 12 ppb	--
	CO	2 ± 1 ppm	2.7 ± 1 ppm
	Total Hydrocarbons	<1 ppm	<1 ppm
Saturday, 2/26 HVAC-on	Air Exchange Rate	2.6 ACH	--
	Temperature	58°F	58°F
	Windspeed	--	--
	Radon	0.02 ± 0.02 pCi/ℓ	--
	Particulate Matter	<10 $\mu g/m^3$	--
	NO$_x$	9 ± 1 ppb	--
	CO	--	--
	Total Hydrocarbons	<1 ppm	--
Wednesday, 3/2	Air Exchange Rate	2.5 ACH	--
	Temperature	--	53°F
	Windspeed	--	2 m/s
	Radon	0.07 ± 0.04 pCi/ℓ	--
	Particulate Matter	123 ± 163 $\mu g/m^3$	--
	NO$_x$	18 ± 4 ppb	--
	CO	2.5 ± 7 ppm	2 ppm
	Total Hydrocarbons	<1 ppm	--
Thursday, 3/3	Air Exchange Rate	--	--
	Temperature	66° F	55° F
	Windspeed	--	2 m/s
	Radon	0.06 ± 0.05 pCi/ℓ	--
	Particulate Matter	196 ± 166 $\mu g/m^3$	--
	NO$_x$	38 ± 32 ppb	--
	CO	3 ppm	--
	Total Hydrocarbons	<1 ppm	--
2/25 - 3/4	Formaldehyde (f)	0.011 ppm	vandalized

(a) Values are in air changes per hour (ACH) ±15%.
(b) Values are in meters per second (m/s).
(c) Values are in picoCuries per liter (pCi/ℓ) (10^{-12} Curies/liter).
(d) Values are in micrograms per cubic meter ($\mu g/m^3$) (10^{-6} g/m^3).
(e) Oxides of nitrogen: NO + NO$_2$; values are in parts per billion (ppb).
(f) Values are in parts per million (ppm), ±15%.

C.4.3 Air Quality Measurements in the Accounting Office in Building #3

Two locations within Building #3 were monitored. The first was in the ground floor accounting office, part of a large two-story building; the second location was a metal/wood/paint shop attached to this two-story building but separated by a fire wall from the accounting office.

Air quality in the first floor accounting office was measured from March 21-23. Sampling lines for continuous measurement of radon and NO_x were located near the center of the office, whereas the instruments were located in the basement of the building. The detector tube for measuring formaldehyde also was located near these sampling lines. Continuous particulate matter measurements were made by placing the instrument on top of a file cabinet (about 5.5 feet above the floor) about 10 feet from the sampling lines. At the same location, hydrocarbons, CO, temperature and relative humidity also were periodically sampled. Air exchange rate measurements were taken each day for the ground floor office.

The instruments for measuring outdoor air quality were located near the main entrance building. A sampling line for NO_x measurements was located on the roof of the building about 30 feet above ground. Windspeed was also taken at this 30-foot elevation. Particulate matter, CO, hydrocarbons, temperature and relative humidity were measured near the instrument location outdoors at 3 feet above ground level. Outdoor measurements were recorded periodically for CO, hydrocarbons, temperature and relative humidity, and continuously for NO_x and particulates during the working hours (only).

Table C.6 gives the indoor and outdoor monitoring record for this location. Table C.7 gives the time average of the monitoring data, including the air exchange rate measurements.

C.4.4 Air Quality Measurements in the Shop Area of Building #3

Air quality in the second location in Building #3, the shop area, was measured from March 23-25. The instruments and sampling lines were located close together. Sampling lines for radon, NO_x, and CO (continuous Miran-80 analyzer) were placed about 6 feet above ground level in the middle of the shop area near a dividing wall between the welding and machining areas. Two

TABLE C.6. Monitoring Record for the First Floor Accounting Office of Building #3

Date	Time	CO_{in} ppm	CO_{out} ppm	NO_x in ppm	NO_x out ppm	HC_{in} ppm	HC_{out} ppm	Radon pCi/ℓ	TSP_{in} µg/m³	TSP_{out} µg/m³	$Temp_{in}$ °F	$Temp_{out}$ °F	RH_{in} %	RH_{out} %	Wind Speed m/s	Air Exchange ACH	Notes
3/21 Monday	1300	3.2	4.4	0.040	0.010			0.25	100	50	70	58	59	70	0-2		1 smoker in office area at most times. Overcast - no rain. 9-10 people, large office; doors to hallways always left open. HVAC system off at 1700 hrs. Restroom (2) vents stay on. HVAC on at 0700. Little traffic in front of building Monday. Air exchange measured with HVAC system off.
	1400	4.0	4.4	0.020	0.018	0.5	lost	0.23	90	80	72		59	82	0-2		
	1500	4.0	5.2	0.020	0.013			0.18	110	60	72						
	1600			0.020	0.012			0.27	116	60	72			100	3-5	0.39	
	1700	4.0	4.4	0.018	0.012			0.25	86		70	52	51	100	0-2	0.39	
	1800	3.2		0.015				0.27	54							0.39	
	1900			0.02				0.27	45								
	2000			0.025				0.29	36								
	2100			0.025				0.35	35								
	2200			0.025				0.35	35								
	2300			0.025				0.34	30								
	2400			0.025				0.24	30								
3/22 Tuesday	0100			0.020				0.48	28								
	0200			0.015				0.45	26								
	0300			0.015				0.70	24								
	0400			0.015				0.82	23								
	0500			0.013				0.67	18								
	0600			0.010				0.62	16								
	0700			0.010				0.60	15								
	0800			0.040				0.79	90								
	0900	4.5	5.4	0.030				0.78	90	16	70	60	61	71	0-2	0.26	1 smoker in office area, office fully occupied. Overcast, rainy, cool.
	1000	4.6	5.4	0.040				0.69	90	14					2-5	0.26	
	1100	4.6	5.4	0.015		0.5	0.4	0.72	80	12					3-5	0.26	
	1200			0.015				0.60	80	12					3-5	0.26	
	1300			0.012	0.014			0.43	80	12					4-7	0.26	
	1400		4.6	0.015	0.013			0.27	80	11	70	58	65	97	4-7	0.26	Office 1/2 full after lunch. Break at 1445-1500. Weather: Cloudy, windy, rainy. At ~1530 passage door to shop area (on 1st floor) opened. Large bay doors in shop also open. Noticed a sharp increase in circulation between basement and 1st floor.
	1500	5.0	5.4	0.010	0.014	0.5	0.4	0.24	110	11					5-8	0.59	
	1600	5.0	5.4	0.040	0.013			0.21	96	12					7-9	0.59	
	1700			0.045				0.16	80	13							
	1800			0.030				0.09	54								
	1900			0.020				0.23	46								
	2000			0.015				0.21	32								
	2100			0.010				0.06	30								
	2200			0.008				0.14	24								
	2300			0.005				0.24	20								
	2400			0.005				0.29	16								
3/23 Wednesday	0100			0.005				0.09	14								
	0200			0.005				0.25	10								
	0300			0.005				0.22	8								
	0400			0.005				0.26	6								
	0500			0.005				0.22	6								
	0600			0.005				0.18	6								
	0700			0.005				0.17	5								
	0800			0.008				0.13	85								
	0900	3.2	5.4	0.015				0.02	90	15	68	49	60	80	4-7	0.45	Windy, rainy
	1000	4.8	5.4	0.020	0.027	0.5	0.4	0.29	98	14					5-8	0.45	Wind Gusts - 9 m/s
	1100	5.3	5.8	0.015	0.027			0.14	110						2-5	0.45	Wind Gusts - 13 m/s
	1200		6.2	0.010	0.012			0.05	70						2	0.45	Wind Gusts - 12-13 m/s
	1300			0.020	0.020			0	80	10		58		70	0-2	0.45	8 people in office, 1 smoker.

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ppm = parts per million
pCi/ℓ = picoCuries per liter
µg/m³ = micrograms per cubic meter
RH = relative humidity
m/s = meters per second
ACH = air changes per hour

TABLE C.7. Summary of Measurements for the First Floor Accounting Office of Building #3

Day/Date/Time	Parameter	Time Average Inside	 Outside
Monday, 3/21 1300 - 1700	Air Exchange Rate(a)	--	--
	Temperature	71°F	55°F
	Relative Humidity	56%	84%
	Windspeed(b)	--	1 m/s
	Radon(c)	0.24 ± 0.03 pCi/ℓ	--
	Particulate Matter(d)	104 ± 13 $\mu g/m^3$	63 ± 13 $\mu g/m^3$
	NO_x(e)	24 ± 9 ppb	13 ± 3 ppb
	CO	3.5 ± 0.4 ppm	4.5 ± 0.4 ppm
	Total Hydrocarbons	<1 ppm	<1 ppm
Tuesday, 3/22 0800 - 1700	Air Exchange Rate	0.45 ACH	--
	Temperature	70°F	59°F
	Relative Humidity	63%	84%
	Windspeed	--	5 m/s
	Radon	0.49 ± 0.25 pCi/ℓ	--
	Particulate Matter	88 ± 10 $\mu g/m^3$	13 ± 2 $\mu g/m^3$
	NO_x	26 ± 14 ppb	13 ± 1 ppb
	CO	4.5 ± 0.5 ppb	5 ± 0.5 ppb
	Total Hydrocarbons	<1 ppm	<1 ppm
Wednesday, 3/23 0800-1300	Air Exchange Rate	0.45 ACH	--
	Temperature	68°F	54°F
	Relative Humidity	60%	75%
	Windspeed	--	4 m/s
	Radon	0.11 ± 0.11 pCi/ℓ	--
	Particulate Matter	89 ± 14 $\mu g/m^3$	13 ± 3 $\mu g/m^3$
	NO_x	15 ± 5 ppb	12 ± 7 ppb
	CO	4.5 ± 1 ppm	5.5 ± 0.5 ppm
	Total Hydrocarbons	<1 ppm	<1 ppm
3/21 - 3/29	Formaldehyde(f)	0.002 ppm	0.001 ppm

(a) Values are in air changes per hour (ACH), ±15%.
(b) Values are in meters per second (m/s).
(c) Values are in picoCuries per liter (pCi/ℓ) (10^{-12} Curies/liter).
(d) Values are in micrograms per cubic meter ($\mu g/m^3$) (10^{-6} g/m^3).
(e) Oxides of nitrogen: NO + NO_2; values are in parts per billion (ppb).
(f) Values are in parts per million (ppm), ±15%.

formaldehyde monitors were placed in the shop area. One was located near the instrument/sampling lines; the other was placed near the entrance to the shop offices, about 100 feet away from the instrument/sampling area. Particulates and hydrocarbons were measured at table height near the sampling lines. Backup carbon monoxide monitoring (using the MINICO® detector) was also performed at table height. Temperature and relative humidity were also measured inside.

A brief summary record of general shop activities was kept during the monitoring period and is noted in the monitoring record (see Table C.8). Continuous measurements were taken of radon, NO_x, and particulate matter. Air exchange rate was measured only once during the monitoring period when the shop (and adjacent accounting office) was unoccupied and all outside doors were closed. This was to ensure that one measurement would be taken of natural infiltration due to leakage through the structure. The measurement continued for 2 hours into the work day. During the entire monitoring period when the shop area was occupied, some of the large bay doors and other small doors were open to allow equipment and people outside access and to supply fresh air to the shop area (because no central HVAC system is installed in the shop).

Outdoor measurements were taken from the same locations as the outdoor measurements taken for the accounting office during March 21-23. The same measurement protocol for outdoor measurements was used as described for the monitoring of that office area.

Table C.8 gives the indoor and outdoor monitoring record for the shop area. Table C.9 gives the daily time average of the monitoring data, including the single air exchange rate measurement.

C.4.5 Air Quality Measurements in Building #4 - Warehouse

The indoor air quality in the warehouse of Building #4 was measured on March 26, 28, and 29. The instruments and sampling lines were located at the center of the warehouse near a wall dividing sections of the warehouse. Sampling lines for radon, NO_x, and CO (Miran-80 instrument) were located about 10 feet above the floor. Particulate matter, total hydrocarbon and backup CO (MINICO®) sampling was from a 3-foot high table nearby. Continuous sampling was performed for radon, NO_x, and CO. Periodic sampling was performed for

TABLE C.8. Monitoring Record for the Shop Area of Building #3

Date	Time	CO_{in} ppm	CO_{out} ppm	NO_x in ppm	NO_x out ppm	HC_{in} ppm	HC_{out} ppm	Radon pCi/ℓ	TSP_{in} µg/m^3	TSP_{out} µg/m^3	$Temp_{in}$ °F	$Temp_{out}$ °F	RH_{in} %	RH_{out} %	Wind Speed m/s	Air Exchange ACH	Notes
3/23	1400				0.010												
Wednesday	1500	[illegible]		0.045	0.005				60	14	58	61		62	0-2		2 bay doors open,* 1 one-half open. 1 welder working, grinding.
	1600	[illegible]	6.6	0.025	0.005				56	14	58				0-2		
	1700			0.04					60								
	1800			0.035					52								
	1900			0.03					51							0.07 NO_x Decay	
	2000			0.028					48							"	
	2100			0.025					45							"	
	2200			0.022					43							"	
	2300			0.021					38							"	
	2400			0.02					34								
3/24	0100			0.018					30								
Thursday	0200			0.017					26								
	0300			0.017					24								
	0400			0.017					20								
	0500			0.016					19								
	0600			0.016					17								
	0700			0.022					16								
	0800			0.065					55	34	60	56	59	80	0-2		2 doors open, lift trucks moved outside, 1 welder working. 2 doors open. No welding, sweeping by inlet to instrument. Released 100 cc SF_6. 1 man drilling. 1 man welding. SF_6 nearly gone - high exchange. 3 doors open, cutting torch used. Welding at 1500 hr-strong odor. 1 door open, 1 door half open, grinding 20 ft from instrument. SF_6 injected at 1630 hr so that infiltration measurement could be done on 3/25 before work.
	0900			0.12					160	30					-		
	1000	4	5	0.16				0.25	100	30					0-2		
	1100	5	8	0.050	0.017			0.11	190	18					0-2		
	1200			0.020	0.013	0.5	0.4	0.05	50						0-1		
	1300	5.5	8.2	0.22	0.012			0.005	35	15	60	67	60	52	0-2		
	1400	5.0	8.5	0.03	0.016			0.09	45	6				52	0-2		
	1500	[illegible]	7	0.015	0.016			0.03	100	[illegible]					2-3		
	1600	4.1	6.3	0.035	0.017	0.4	0.4	0.03	110								
	1700			0.025				0.11	65								
	1800			0.01				0	30								
	1900			0.007				0.07	30								
	2000			0.005				0.05	25							0.11 NO_x Decay	
	2100			0.005				0.07	20							"	
	2200			0.005				0.09	16							"	
	2300			0.005				0.07	14							"	
	2400			0.005				0.12	12							"	
3/25	0100			0.005				0.16	10								
Friday	0200			0.005				0	10								
	0300			0.005				0.06	9								
	0400			0.005				0.17	8								
	0500			0.005				0.24	7								SF_6 is well mixed.
	0600		5.2	0.005	0.004			0.14	16	16	62	50		88	0-1	0.12 SF_6 Decay	
	0700	5.0	4.6	0.005	0.012			0.12	17	20					0-1		
	0800	[illegible]	4.6	0.065	0.040	0.5	0.5	0.16	18	30					0-1	"	1 man welding. 3 bay doors open; grinding/cutting 20 ft away.
	0900	[illegible]		0.30	0.030			0.05	90	29						5.5 SF_6 Decay	
	1000	5.5	5.0	0.01	0.016			0.04	140	23				4-6			
	1100	6.0	6.2	0.06	0.010			0.05	100	11				0-5			
	1200	5.5		0.05	0.012			0.005	50								
	1300	5.8		0.085	0.012			0.03	68								
	1400	4.2	7.1	0.015	0.010			0	60	11							

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ppm = parts per million
pCi/ℓ = picoCuries per liter
µg/m^3 = micrograms per cubic meter
RH = relative humidity
m/s = meters per second
ACH = air changes per hour

TABLE C.9. Summary of Measurements for Shop Area of Building #3

Day/Date/Time	Parameter	Time Average	
		Inside	Outside
Wednesday, 3/23 1400-1700 hr	Temperature	58°F	61°F
	Windspeed(a)	--	--
	Relative Humidity	--	62%
	Radon(b)	--	--
	Particulate Matter(c)	59 ± 2 $\mu g/m^3$	14 $\mu g/m^3$
	NO_x(d)	37 ± 10 ppb	7 ± 3 ppb
	CO	4 ppm	6.6 ppm
	Total Hydrocarbons	--	--
Thursday, 3/23 0800-1600 hr	Temperature	60°F	62°F
	Windspeed	--	--
	Relative Humidity	60%	61%
	Radon	0.08 ± 0.08 pCi/ℓ	--
	Particulate Matter	94 ± 54 $\mu g/m^3$	22 ± 11/$\mu g/m^3$
	NO_x	57 ± 50 ppb	15 ± 2 ppb
	CO	4.6 ± 0.7 ppm	7.1 ± 1 ppm
	Total Hydrocarbons	0.45 ppm	0.4 ppm
Friday, 3/24 0800-1400 hr	Air Exchange Rate(e)	0.12 ACH (0500-0800 hr)	--
		5.5 ACH (0800-0900 hr)	--
	Windspeed	--	--
	Relative Humidity	--	88%
	Radon	0.05 ± 0.05 pCi/ℓ	--
	Particulate Matter	75 ± 39 $\mu g/m^3$	22 ± 10 $\mu g/m^3$
	NO_x	84 ± 99 ppb	19 ± 12 ppb
	CO	4.8 ± 1 ppm	5.7 ± 1 ppm
	Total Hydrocarbons	0.5 ppm	0.5 ppm
3/23 - 3/29	Formaldehyde(f)	0.002 ppm	0.001 ppm

(a) Values are in meters per second (m/s).
(b) Values are in picoCuries per liter (pCi/ℓ) (10^{-12} Curie/liter).
(c) Values are in micrograms per cubic meter ($\mu g/m^3$) (10^{-6} grams/m^3).
(d) Oxides of nitrogen: NO + NO_2, values are in parts per billion (ppb).
(e) Values are in air changes per hour (ACH), ±15%.
(f) Values are in part per million (ppm), ±15%.

total hydrocarbons and CO (using the MINICO® detector). Three formaldehyde detector tubes were placed in the warehouse: one near the sampling instrument location, one near the receiving/dock area, and one near the warehouse offices. Each tube was placed about 6 feet above the ground. Temperature and relative humidity were also measured inside.

Air exchange rate was only measured during one day using SF_6 tracer gas, when the building (warehouse and office) was unoccupied. Like the shop area in Building #3, this building has no central HVAC system and the large bay doors are used for ventilation as well as for allowing equipment to be moved. The natural air exchange rate was also estimated (for nonworking hours) by examining the continuous CO and NO_x monitoring data and calculating the rate of decay of each pollutant (generated by warehouse activity) after the activity in the warehouse had ceased for the day. The measure of the decay of NO_x and CO was taken only as an estimate of natural infiltration since decay of these chemicals is a combination of chemical transformation and deposition, plus the dilution (or exchange) with outside air.

Outdoor air quality was measured near the loading dock area outside the warehouse. A sampling line for NO_x was placed on the roof about 30 feet above ground level. Windspeed was also taken at this location. Particulates, CO (MINICO®) and total hydrocarbons were measured from a 3-foot high table located on the dock. Formaldehyde was measured using the detector tube located near the entrance to Building #3. Temperature and relative humidity were also measured from the loading dock.

Table C.10 gives the indoor and outdoor monitoring record for the warehouse. Table C.11 gives the daily time average of the monitoring data, including the air exchange rate measurements.

TABLE C.10. Monitoring Record for the Warehouse in Building #4

Date	Time	CO$_{in}$ ppm	CO$_{out}$ ppm	NO$_x$ in ppm	NO$_x$ out ppm	HC$_{in}$ ppm	HC$_{out}$ ppm	Radon pCi/ℓ	TSP$_{in}$ μg/m^3	TSP$_{out}$ μg/m^3	Temp$_{in}$ °F	Temp$_{out}$ °F	RH$_{in}$ %	RH$_{out}$ %	Wind Speed m/s	Air Exchange ACH	Notes
3/26 Saturday	0800	3.6		0.060				0.21	14		54	45	55		0-2	NO$_x$ decay: 0300 3/26- 0700 3/27 0.04	No activity on Saturday. Warehouse contains diesel propane and electric lift trucks. Occasional auto also passes through. Outdoor parameters measured on loading dock, NO$_x$ and wind speed on roof 25 ft above dock, HC TSP and CO at dock level.
	0900	3.6		0.055				0.27	14								
	1000	3.6		0.055		0.5		0.28	14								
	1100			0.050				0.28	14								
	1200			0.045				0.35	14								
	1300			0.045				0.35	13								
	1400			0.040				0.40	13								
	1500			0.040				0.36	12								
	1600			0.038				0.50	12								
	1700			0.035				0.28	12								
	1800			0.032				0.30	12								
	1900			0.032				0.38	12								
	2000			0.030				0.48	12								
	2100			0.030				0.30	12								
	2200			0.030				0.27	12								
	2300			0.030				0.26	11								
	2400			0.030				0.31	11								
3/27 Sunday	0100			0.028				0.33	11								
	0200			0.028				0.29	11								
	0300			0.025				0.27	11								
	0400			0.025				0.27	11								
	0500			0.022				0.35	11								
	0600			0.020				0.38	10								
	0700			0.020				0.33	10								
	0800			0.016				0.28	10								
	0900			0.017				0.21	10								
	1000-2400			0.015				0.04-0.38	8								
3/28 Monday	0100-0700			0.015				0.15-0.26	6								
	0800			0.015				0.19	16	28	53	48	49	90	0-2		
	0900	6.3	4.0	0.10				0.17	40	30					0-2		
	1000	9.7	2.6	0.37		0.5	0.4	0.19	60	36					0-2		
	1100	10.3	4.0	0.54	0.015			0.23	180	18							
	1200	9.7		0.46	0.015			0.21	80								
	1300	10.6		0.44	0.013			0.21	70								
	1400	15.1	3.4	0.82	0.012			0.24	70	20	57	48	59	90	0-2		Rain.
	1500	14.6		0.79	0.012			0.06	132	28						CO decay: 1700 3/28- 0700 3/29 0.05	
	1600	13.6	3.8	0.76	0.010	lost	0.4	0.05	136	22							
	1700	12.8		0.66				0.18	110								
	1800	11.3		0.58				0.23	100								
	1900	12.0		0.52				0.34	90								
	2000	10.3		0.46				0.24	80							NO$_x$ decay: 1600 3/28- 0600 3/29 0.03	
	2100	9.9		0.42				0.17	70								
	2200	9.0		0.38				0.30	52								
	2300	10.1		0.34				0.27	55								
	2400	8.2		0.32				0.29	54								
3/29 Tuesday	0100	8.0		0.28				0.30	50								
	0200	8.2		0.26				0.32	40								
	0300	7.3		0.22				0.27	30								
	0400	6.2		0.20				0.29	29								
	0500	6.4		0.18				0.38	29								
	0600	5.9		0.17				0.26	27								
	0700	6.4		0.14				0.29	24								
	0800	5.2	4.0	0.14				0.36	24	18	54	48		100	0-2	SF$_6$ decay: 0.05 0800- 1100	Rained very hard. Doors only opened briefly during the day. Some lift truck activity.
	0900	6.0	4.0	0.42	0.010			0.41	50	22					0-1		
	1000	6.6	4.0	0.37	0.010	lost		0.41	80	24					0-2		
	1100	7.2	4.0	0.36	0.008			0.35	120	14							
	1200	9.5	4.0	0.40	0.009			0.38	100						4-7		
	1300	8.5	4.0	0.46	0.026			0.46	97	10					2-4	SF$_6$ decay: 0.2 1200- 1500	Doors open periodically but no more than in morning. Increased wind velocity.
	1400	8.0		0.56	0.013			0.45	160	10							
	1500	10.3	4.0	0.79				0.31	170								

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ppm = parts per million
pCi/ℓ = picoCuries per hour
μg/m^3 = micrograms per cubic meter
RH = relative humidity
m/s = meters per second
ACH = air changes per hour

TABLE C.11. Summary of Measurements in the Warehouse of Building #4

Day/Date/Time	Parameter	Time Average Inside	 Outside
Saturday, 3/26			
0800-1600	Air Exchange Rate [a]	0.04 ACH (NO_x decay)	--
0800	Temperature	54°F	45°F
0800	Windspeed [b]	--	2 m/s
0800	Relative Humidity	55%	--
0800-1600	Radon [c]	0.3 ± 0.08 pCi/ℓ	--
0800-1600	Particulate Matter [d]	13 ± 1 $\mu g/m^3$	--
0800-1600	NO_x [e]	48 ± 8 ppb	--
0800-1000	CO	3.6 ppm	--
0800-1000	Total Hydrocarbons	0.5 ppm	--
Sunday, 3/27	Air Exchange Rate	0.04 ACH (NO_x decay)	--
0800-1600	Radon	0.21 ± 0.1 pCi/ℓ	--
	Particulate Matter	8 ± 1 $\mu g/m^3$	
	NO_x	15 ± 1 ppb	--
Monday, 3/28	Temperature	55°F	48°F
0800-1600	Windspeed	--	2 m/s
	Relative Humidity	54%	90%
	Radon	0.17 ± 0.07 pCi/ℓ	--
	Particulate Matter	87 ± 52 $\mu g/m^3$	26 ± 6 $\mu g/m^3$
	NO_x	477 ± 289 ppb	13 ± 2 ppb
	CO	11 ± 3 ppm	3.6 ± 0.6 ppm
	Total Hydrocarbons	0.5 ppm	0.4 ppm
Tuesday, 3/29	Air Exchange Rate	0.2 ACH (SF_6 decay)	--
0800-1500	Temperature	54°F	48°F
	Windspeed	--	2 m/s
	Relative Humidity	--	100
	Radon	0.35 ± 0.06 pCi/ℓ	--
	Particulate Matter	100 ± 50 $\mu g/m^3$	16 ± 6 $\mu g/m^3$
	NO_x	438 ± 185 ppb	13 ± 7 ppb
	CO	7.7 ± 2 ppm	4.0 ppm
	Total Hydrocarbons	lost	--
3/25 - 3/29	Formaldehyde [f]	0.006 ppm	0.001 ppm

(a) Values are in air changes per hour (ACH), ±15%.
(b) Values are in meters per second (m/s).
(c) Values are in picoCuries per liter (pCi/ℓ) (10^{-12} Curies/liter).
(d) Values are in micrograms per cubic meter ($\mu g/m^3$) (10^{-6} g/m^3).
(e) Oxides of nitrogen: NO + NO_2, values are in parts per billion (ppb).
(f) Values are in parts per million (ppm), ±15%.

APPENDIX D

AIR QUALITY ANALYSIS

APPENDIX D

AIR QUALITY ANALYSIS

This appendix presents specific information on factors related to indoor air quality. Long-term average concentrations of indoor pollutants are computed for both commercial buildings designed to ASHRAE Standard 90A-1980 and to the proposed standard. To use these computations, both building ventilation rates and indoor pollutant source terms had to be identified. Source term emanation rates were both continuous (e.g., radon and formaldehyde) and intermittent (e.g., particulates, carbon monoxide, and carbon dioxide from smoking). Techniques for evaluating these sources and their emanation rates are described in the following sections, along with assumptions on the type and amount of building materials expected in a building.

D.1 APPROACH

Indoor air quality values were computed for two cases: the baseline design case and the proposed standard design case. The baseline case refers to test buildings designed and evaluated by computer simulation using ASHRAE Standard 90A-1980, the energy conservation standard currently in use. The redesign case refers to the same buildings redesigned to the proposed standard. The 10 test buildings were used to develop and test the proposed standard in a computer simulation that is described more completely in Chapter 1 of this analysis.

A range of indoor pollutant concentrations was computed for each case: low, typical, and max. These values represent the range of emission rates that are expected for each pollutant, based on the most recent literature available.

D.2 POLLUTANT EMANATION RATES

Source terms are defined as the pollutant's (gaseous or particle) emanation rate, in mass per unit time, from the source releasing the pollutant. In general, source term data are used in mathematical formulae along with data on room volume and air change/hour (ACH) to calculate indoor concentrations of pollutants. In practice, to simplify the computation, emanation rates were changed to emission rates per unit area for each specific pollutant. Computational procedures for accomplishing this are described in detail below.

Many factors that were largely irrelevant to the comparison of the ASHRAE Standard 90A-1980 design and proposed standard design were given assumed values to allow the concentrations to be computed. When an important factor had a large range and could not be uniquely defined for each type of building, a uniform value was adopted for all structures. Two examples are 1) the handling of outdoor ambient pollutant concentrations and 2) the removal of pollutants within buildings.

D.2.1 Method to Evaluate Continuous Sources

Continuous sources of contaminants were calculated by a simple steady-state approach. Emanation rates from soils and building materials for contaminants such as radon and formaldehyde are available in the literature. These rates are usually given as mass emission per time from either a surface area or a mass of material.

Equations for calculating pollutant concentrations at steady state take the following general form (typical units shown below in parentheses):

$$\begin{array}{c}\text{Pollutant}\\ \text{Concentration}\\ \text{For Each Source}\end{array} = \begin{array}{c}\text{Emanation}\\ \text{Rate}\end{array} \times \begin{array}{c}\text{Mass of}\\ \text{Emanating}\\ \text{Material}\end{array} \div \begin{array}{c}\text{Fresh Air}\\ \text{Exchange}\\ \text{Rate}\end{array} \div \begin{array}{c}\text{Building}\\ \text{Volume}\end{array}$$

$$(\mu g/m^3) = \frac{g}{kg\ hr} \times (kg) \div (\frac{1}{hr}) \div (m^3)$$

When literature surveys yielded a range of values for emanation rates, maximum values are used to determine "worst-case" situations.

The relationship for computation of concentration from a number of indoor sources for one pollutant is:

$$C = C_0 + \sum_{i = 1,S} \frac{(E_i \; M_i)}{V \; I} \qquad (D.1)$$

where

C = long term average pollutant concentration

C_0 = average annual pollutant concentration in outdoor fresh air supply

E = emanation rate for pollutant source material, i

M = mass of emanating material, i

S = number of sources of the pollutant in the building

V = volume of building

I = the fresh air exchange rate for the pollutant.

Co is the outdoor concentrations reduced by any air cleaning equipment on the intake air. The fresh air exchange rate is computed for each pollutant using

$$I = (T + R\ f)/V \qquad (D.2)$$

where

T = the volume of outdoor air supplied per unit time within the building

R = recirculation flow

f = average removal efficiency for filtration on recirculating air

V = volume of building.

Suspended particulates (including combustion products from cigarette smoking) were modeled both without any filtration ($f = 0$) and with a typical filtration rate of 0.9 to examine the effectiveness of this control strategy. Filtration effects were not computed for other indoor pollutants.

Relationships are given below for each pollutant based on equations (D.1) and (D.2). To make computations easier, the emanation rates from some materials were converted to emission rates from surface areas or mass.

Using the expressions given above, pollutant concentrations were computed for both the baseline and proposed standard (or redesign) cases. The increment of change in pollutant concentrations between these two cases represents the estimated effect resulting from the use of the proposed standard.

D.2.2 Pollutant Source-Term Information

The following sections present additional details on the pollutants addressed in the computation of indoor air quality. Table D.1 lists the source terms for the calculations of indoor air concentrations of those pollutants.

Radon

The source terms for radon pertain to gaseous ^{222}radon (^{222}Rn) and are all assumed to be steady state (see Table D.1). Radon will decay into alpha-emitting daughter products called radon progeny. In this series, ^{238}U decays to thorium (^{234}Th), which in turns decays to protactinium (^{234m}Pa), etc., until the series stops at stable lead (^{206}Pb). Uranium is found in trace levels in earthen building materials, soil and at higher levels in mineralized areas. Consequently, radon gas also is found in these materials and readily diffuses into the atmosphere. Radium (^{226}Ra), the predecessor to ^{222}Rn in the series, is relatively soluble in water.

The greatest single source of radon is from the soil. Source terms from the soil range from 0.1 to 1 pCi/m^2/sec in the low-radon areas to 1 to 10 pCi/m^2/sec in high-radon localities (Bruno 1981). Radon is also released from the aggregate contained in concrete. Release rates range from 0.02 to 0.06 pCi/m^2/sec for each side of a 0.2-meter-thick wall (Hollowell 1981). A concrete slab on soil will emanate radon both from the concrete aggregate and from the diffusion of the radon from the soil through the pores of the concrete. The magnitude of the source term depends on whether the slab is on soil in a mineralized or nonmineralized area because of the variation in radon emanation from the soil in these two areas. Brick (adobe and red) building material is also a source of gaseous radon. In the 10 test buildings, walls less than 5 inches thick were assumed to be wood; all others were assumed to be concrete.

Another major source of indoor radon is well water. Radon dissolves in water and will remain dissolved until the water is vented. Assuming the water is unvented before it is used in the building, the magnitude of radon released

TABLE D.1. Pollutant Source Terms for Indoor Air Concentration Calculations

Pollutant	Source	Emanation Rate or Concentration	Comments	References
Radon (^{222}Rn)	Soil	0.1 to 1 pCi/m^2/sec	Nonmineralized region	Bruno 1981
	Soil	1 to 10 pCi/m^2/sec	Mineralized locality	Bruno 1981
	Soil (under concrete slab)	0.01 to 0.1 pCi/m^2/sec	Nonmineralized region	Bruno 1981
	Soil (under concrete slab)	0.1 to 1 pCi/m^2/sec	Mineralized locality	Bruno 1981
	Concrete	0.4 to 1.2 pCi/kg/hr	All areas of country	Hollowell 1981
	Brick	0.10 to 0.35 pCi/kg/hr	Includes red and adobe	Hollowell 1981
	Wood	0.02 pCi/kg/hr	Mean--western wood	Hollowell 1981
	Well water	10,000 pCi/ℓ	Average nationwide concentration	U.S. EPA 1979
	Surface water	0 to 14 pCi/ℓ	Columbia River and tributaries	Soldat 1961
Organics	Carpet	1.0 mg/h/ft^2		Miksch 1982
	New building materials	10 g/h	Nominal emission rate	Miksch 1982
Formaldehyde (HCHO)	Particle board	0.4-8.1 µg/g/day		Gupta 1982
	Plywood	0.03-9.2 µg/g/day		Gupta 1982
	Paneling	0.84-2.1 µg/g/day		Gupta 1982
	Fiberglass insulations	0.3-2.3 µg/g/day		Gupta 1982
	Clothing	0.2-4.9 µg/g/day		Gupta 1982
	Drapery	(1)-3.0 µg/g/day		Gupta 1982
	Paper products	0.03-0.36 µg/g/day		Gupta 1982
	Carpet	(1)-0.06 µg/g/day		Gupta 1982
	Tobacco smoking	1 mg/cigarette	Average	NRC 1981a
	Gas stove	25 mg/hr	Average-oven	NRC 1981a
		15 mg/hr	Average per burner	NRC 1981a
		12 mg/hr	National average	NRC 1981b
Benzo-[a]-pyrene	Tobacco smoking	1.7 x 10^{-4} mg/cig.	Average respirable particulates	NRC 1981a
	Outdoor	0.1 ng/m^3	Average, rural areas - no coking areas	Moschandreas 1981
Carbon Monoxide (CO)	Tobacco smoking	105 mg/cigarette	Average sidestream plus mainstream	NRC 1981a
	Gas stove	1.3 to 3 g/hr	Oven	Girman 1981
		1.8 to 2.7 g/hr	Per burner	Girman 1981
Carbon Dioxide (CO$_2$)	Tobacco smoking	143 mg/cigarette	Average sidestream plus mainstream	NRC 1981a
	Gas stove	383 to 400 g/hr	Oven	Girman 1981
		483 to 550 g/hr	Per burner	Girman 1981
Nitric Oxide (NO)	Gas stove	0.03 to 0.09 g/hr	Oven	Girman 1981
		0.05 to 0.12 g/hr	Per burner	Girman 1981
	Outdoor	274 µg/m^3	1-hr maximum	
		48 µg/m^3	Annual arithmetic mean	
Nitrogen Dioxide (NO$_2$)	Gas stove	0.08 to 0.13 g/hr	Oven	Girman 1981
		0.17 to 0.25 g/hr	Per burner	Girman 1981
Nitrogen Oxides (as NO$_2$)	Gas stove	0.13 to 0.27 g/hr	Oven - calculated from NO and NO$_2$ data	
		0.25 to 0.14 g/hr	Per burner - calculated from NO and NO$_2$ data	
	Tobacco smoking	0.065 mg/cigarette	Mainstream and sidestream average	NRC 1981a
Respirable Particulate Matter	Tobacco smoking	10.8 mg/cigarette	Average sidestream	NRC 1981a
	Gas stove	0.01 to 0.03 g/hr	Per burner	Girman 1981

from water within the building will depend on the radon concentration in water (Table D.1), the number of occupants, and their water usage (washing, flushing, showering). Radon emission rates were selected to cover the expected range in commercial buildings. The greatest variability in radon source terms is associated with geological features (water supply and substrate); considerably less variability occurs in the building materials (Sachs, Hernandez and Ring 1982; Abu-Jarad and Fremlin 1982). Soil and concrete emission rates covering a range from nonmineralized to mineralized areas are used. Ambient outdoor radon concentrations show considerable variation due to soil and weather factors. A typical background value was chosen for this computation. It was assumed that the water supplies for the test commercial buildings are from surface sources.

Formaldehyde

The source strength of formaldehyde from building materials and furnishings/carpet decreases with time, based on an emanation half-life for formaldehyde of 58 months (NRC 1981b; Gupta, Ulsamer and Preuss 1982). Other factors that influence release rates are the emanation rate of formaldehyde from materials. Recorded measurements of formaldehyde concentrations (for both mobile homes and other dwellings) in Table D.1 are not correlated with home age, temperature, humidity, or the amount of formaldehyde-emitting materials in the structure. They do, however, represent a typical range of values.

Although urea-formaldehyde foam insulation (UFFI) is known to be a possible major source of formaldehyde, currently UFFI is seldom used in new construction. Various other insulation materials were used in the design modifications of the test buildings considered here. Some organic emissions will occur from these materials.

Formaldehyde is also a combustion product for such common substances as natural gas and tobacco. Typical emission rates range from 15 to 25 mg/hr for gas stoves and 1 mg/cigarette (NRC 1981a).

Formaldehyde concentrations that are normally found in the atmosphere are generally well below the detectable limits of measuring devices (5 $\mu g/m^2$). Atmospheric formaldehyde is not considered a major source for indoor air concentrations when compared with combustion and/or building material source terms. In normal working environments, formaldehyde concentrations range from 50 to 60 μg/m^3 (DOE 1980).

Table D.2 summarizes recently measured values levels of formaldehyde in occupational environments considered to have unusually high sources of formaldehyde.

Other Organics

In addition to formaldehyde, the indoor environment can contain a broad spectrum of other organic contaminants. The sources include building materials, wet-process photocopiers, tobacco smoke, and building maintenance materials. Table D.3 lists specific organic contaminants found in studies of offices (Miksch, Hollowell and Schmidt 1982). Similar data are available for a preschool (Berglund, Johansson and Lindvall 1982).

Molhave (1982) presents rates for emission of numerous organic gases and vapors from 42 building materials. These rates provided the basis for estimating organic contaminant emission rates for changes in building materials.

TABLE D.2. Formaldehyde Measurements in Occupational Environments (NRC 1981b)

Sampling Site	Concentration (μg/m^3) Range	Mean
Textile plants(a)	0-3,200	800
Garment factor(a)	1,060-3,200	--
Clothing store	1,060-3,900	--
Smog chamber(a)	12-unknown	--
Laminating plants(a)	47-13,000	--
Funeral homes	106-6,200	300-1,600

(a) Specific activities are not included in commercial air quality modeling; value provided only for comparison purposes.

TABLE D.3. Specific Organic Contaminants Detected in Four Office Office Sites at Lawrence Berkeley Laboratory (LBL) (Miksch, Hollowell and Schmidt 1982)

	LBL 67C(a)	LBL 90H(a)	LBL 90-3143(b)	LBL 90-3145(c)
Hydrocarbons				
n-Hexane	X	X	X	
n-Heptane			X	
n-Octane			X	X
n-Nonane			X	X
n-Undecane			X	X
2-Methylpentane	X	X		
3-Methylpentane		X		
2.5-Dimethylheptane			X	
Methylcyclopentane	X	X	X	
Ethylcyclohexane			X	X
Methylcyclohexane			X	
Pentamethylheptane			X	X
Aromatics				
Benzene		X	X	
Xylenes	X			
Toluene		X	X	X
Halogenated hydrocarbons				
Trichloroethane	X	X	X	X
Trichloroethylene	X		X	X
Tetrachloroethylene		X	X	
Miscellaneous				
Hexanal		X		
Methylethylketone	X			

(a) Office trailer.
(b) Remodeled office inside a large building.
(c) Existing office inside a large building.

Suspended Particulate Matter

Tobacco smoke is a major contributor to the indoor concentration of respirable particulate matter (RSP) (particles less than 3.5 μm in diameter). An average of 18 μg of particulates per mg of tobacco has been reported for sidestream cigarette smoke (Girman et al. 1982, p. 215). Based on 600 mg of fuel per cigarette, smoking a cigarette will generate 11 mg of particulates. Gas stoves contribute RSP emissions ranging from 0.01 to 0.03 g/hr (Girman et al. 1981). Normally, RSP produced by furnaces, boilers, and gas stoves is vented directly outdoors in commercial buildings. Therefore, in this analysis, it was assumed that direct outside venting removed suspended particulates from all sources but cigarette smoke.

Commercial buildings typically use low-efficiency filters that remove only a small fraction of RSP. Typically, RSP concentrations from tobacco smoke are reduced only 0.3% to 3.0% by these low-efficiency filters. Where ambient outdoor air quality falls below EPA outdoor particulate standards, higher-efficiency filters are generally required to clean outdoor air before its use as supply air. The effect of high-efficiency filters capable of removing 90% of suspended particulate matter were included in the model for this analysis. This level of filtration dramatically reduced estimated levels of indoor TSP.

Benzo-[a]-pyrene

The major source of benzo-[a]-pyrene (BaP) in indoor air is again tobacco smoke. An average of 1.7×10^{-4} mg/cigarette of BaP has been measured. Outdoor levels of BaP contribute very little to indoor concentrations (NRC 1981b).

Oxides of Nitrogen (NO, NO_2)

Combustion products from gas stoves are a primary potential source of oxides of nitrogen (see Table D.1). As shown in Table D.1, estimated values for NO_2 range from 0.17 to 0.25 g/hr for a burner, and from 0.08 to 0.13 g/hr for the oven. A NO_2 source term for tobacco smoking has also been measured and averages 0.065 mg/cigarette.

Carbon Monoxide (CO)

The greatest indoor source of carbon monoxide is combustion. Carbon monoxide emissions range from 1.3 to 3 g/hr for steady-state operation of a gas stove oven and 1.8 to 2.7 g/hr for a gas stove burner (Girman et al. 1981).

Tobacco smoke is also a minor source of carbon monoxide. An average of 105 mg is emitted per cigarette. This average includes sidestream CO as well as CO inhaled and exhaled during smoking. A major fraction of elevated CO levels is often from outdoor sources. Indoor sources tend to be small, except in buildings with underground parking facilities, where automobile exhaust can be a major contribution to CO found within the building.

Carbon Dioxide (CO_2)

Most indoor CO_2 is generated by metabolic activity. In addition to that source, combustion sources (stoves and cigarettes) contribute the greatest amount of carbon dioxide to indoor air. An average emission of 143 mg CO_2/-cigarette has been measured for the combined mainstream and sidestream CO_2 (NRC 1981a).

D.3 EMANATION RATES

Table D.1 summarizes the release rate values obtained from the literature for radon, formaldehyde, CO, CO_2, airborne particles, and other indoor pollutants.

D.4 BUILDING CHARACTERISTICS AND ASSUMPTIONS

The computations of indoor pollutant concentrations required input of building characteristics for each of the test buildings. These data included physical dimensions, building materials, fresh and forced air flow rates, building occupancy, and building usage numbers. Table 3.1 in the main text contains the building input values used in assessing indoor air pollutant concentrations. Table D.4 summarizes other building parameters required to apply the source terms given in Table D.1.

In an effort to represent a range of climates, material and labor costs, etc., across the United States, five cities were used as hypothetical locations

TABLE D.4. Summary of Building Characteristics and Assumptions for Buildings in Seattle

Building Name	Carpet Floor Area, (ft^2)	Number of Occupants	Average Smoker Fraction	Number of Water Fixtures	Fiberglass Mass		Plywood Mass
					ASHRAE Standard 62-1981 (kg)	Proposed Standard (kg)	(kg)
Small office	1,488	19	0.3333	5	1,220	408	1,840
Medium office	34,155	330	0.3333	57	3,450	3,450	0
Large office	24,845	3,972	0.3333	716	0	0	0
Retail store	106,730	2,008	0.3333	40	0	0	0
Strip store	5,875	286	0.3333	6	2,050	4,100	0
Apartment house	166,710	1,310	0.3333	(a)	0	0	14,900
Hotel	152,490	2,900	0.3333	1,604	6,310	2,330	0
Warehouse, storage	0	20	0.3333	13	0	0	14,900
Warehouse, offices	1,478	16	0.3333	0	951	705	1,450
Assembly building	9,198	614	0.2500	18	3,770	2,310	9,000
School	35,473	2,161	0.0166	182	9,390	12,900	21,600

(a) Water usage based on 90 gal/day/occupant, rather than on the number of fixtures.

for the test buildings. Only two of the parameters that were used to compute the indoor air quality changes were affected by the differences among the five climates: the recirculated air flow rate and the type/amount of insulation material. These parameters affect the impact that filters will have on removing particulates from recirculated air and the source term for pollutants released from insulation materials.

The test building characteristics derived for Seattle were selected to evaluate the proposed standard's effect on indoor air quality for pollutants having the same sources or fresh air ventilation rates in all the cities. The only variations were minor differences in the effectiveness of filtration of recirculated air. However, the changes in insulation material specified for the test buildings in the various cities did cause different estimated rates of organic emissions within the buildings. Therefore, total indoor organic pollutant concentrations were evaluated for each of the five cities.

A gas stove with an oven was assumed to be in each unit of the apartment building as well as in the kitchen of the assembly building. The stoves were assumed to operate several hours per day and no credit was given for possible external venting. Kitchen emissions in all other commercial buildings were assumed to be externally vented and not a source of indoor air pollutants in the rest of the building.

Using the data derived from the literature (shown in Table D.1), minimum (min), typical and maximum (max) emission rates for the various major sources were defined using the criteria discussed in the main text. Table D.5 summarizes the emission rates used to evaluate indoor pollutant concentrations. Table 3.4 in Chapter 3 gives organic emission rates for building insulation materials.

TABLE D.5. Summary of Pollutant Emission Values Used in Computing Indoor Air Quality Computations

Pollutant	Source	Min	Typical	Max	Units
Radon	Concrete	0.4	0.7	1.2	pCi/kg/hr
Radon	Red brick	0.1	0.1	0.1	pCi/kg/hr
Radon	Adobe brick	0.35	0.35	0.35	pCi/kg/hr
Radon	Sfc water	0	7	14	pCi/l
Radon	Mix soil	0.1	0.32	10	$pCi/m^2/s$
Particulate	Tobacco sm	10.8	10.8	10.8	mg/cigarette
Particulate	Gas stove	10	17	30	mg/brnr-hr
Formaldehyde	Tobacco sm	1	1	1	mg/cigarette
Formaldehyde	Gas oven	25	25	25	mg/oven-hr
Formaldehyde	Gas stove	15	15	15	mg/brnr-hr
Formaldehyde	Plywood	0.03	0.5	9.2	ug/g/day
Formaldehyde	Fiberglass	0.3	0.8	2.3	ug/g/day
Formaldehyde	Carpet	0	0	0.06	ug/g/day
CO	Tobacco sm	86	86	86	mg/cigarette
CO	Gas oven	1,300	2,000	3,000	mg/oven-hr
CO	Gas stove	1,800	2,200	2,700	mg/brnr-hr
CO_2	Tobacco sm	80	80	80	mg/cigarette
CO_2	Gas oven	383,000	391,000	400,000	mg/oven-hr
CO_2	Gas stove	483,000	515,000	550,000	mg/brnr-hr
CO_2	Respir	8.91	8.91	8.91	mg/s/person

The radon computation assumed the following building material densities: concrete density, 143 lb/ft^3 (2304 kg/m^3) (Eschbach 1956); wood density, 27 lb/ft^3 (435 kg/m^3); and brick density 94 lb/ft^3 (1520 kg/m^3) (Lang 1956).

D.5 FRESH AIR VENTILATION RATES

Fresh air ventilation rates for each building are based on minimum rates given in ASHRAE codes (Table D.6). Table 3.1 contains average ventilation rates. These rates are weighted averages of the fresh air supplies for the sections of each building as derived from Table D.6.

In addition to variation by usage, this standard gives different rates for smoking and nonsmoking areas. The approach used for this analysis was to assume that tobacco smoking will occur in most parts of the buildings except those designated as nonsmoking by the ASHRAE Standard 62-1981. The classrooms in the school and the chapel area of the assembly building also are assumed to be nonsmoking areas. Although this approach follows current practices, trends indicate that more areas may be designated nonsmoking in the future.

The source terms for pollutants resulting from cigarette smoking are based on the total number of smokers in each building. One-third of the occupants in smoking areas are assumed to be smokers. No smoking is assumed to occur in the nonsmoking areas.

With the exception of the storage area in the warehouse, all the fresh air supplied within the buildings is assumed to be from the forced air ventilation system with no infiltration of outdoor air. Although changes in windows, insulation, roofing, etc., may change the tightness of the building envelope, no change was assumed to occur in the total fresh air supply within the building.

Computed fresh air supply rates were used instead of literature-derived rates for several reasons. Ventilation data are not available for all the proposed building categories. For the types of commercial buildings having data available, there is usually a wide range of values. Also, the reported data are usually insufficient to evaluate the appropriateness of those values for the test buildings used in this analysis. Computing the infiltration rates from the codes provided a consistent method of generating comparable fresh air

TABLE D.6. ASHRAE Standard 62-1981 Recommended Fresh Air Supply Rates

	Estimated Occupancy, persons per 1000 ft^2 or 100 m^2 floor area. Use only when design occupancy is not known	Outdoor Air Requirements				
		Smoking	Non-smoking	Smoking	Non-smoking	Comments
Dry Cleaners and Laundries		cfm/person		L/s · person		
Commercial	10	—	15	—	7.75	A blank (—) indicates that smoking (or non-smoking) in a space should not occur.
Storage, pick-up areas	30	35	10	17.5	5	
Coin-operated Laundries	20	35	15	17.5	7.5	Dry cleaning processes may require more air
Coin-operated dry cleaning	20	—	15	—	7.5	
Food & Beverage Services						
Dining rooms	70	35	7	17.5	3.5	
Kitchens	20	—	10	—	5	
Cafeterias, fast food facilities	100	35	7	17.5	3.5	
Bars and cocktail lounges	100	50	10	25	5	
Garages, auto repair shops, service stations		cfm/ft^2 floor		L/s · m^2 floor		
Parking garages (enclosed)	—	1.5	1.5	7.5	7.5	Distribution must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal.
Auto Repair workrooms (general)	—	1.5	1.5	7.5	7.5	
Hotels, Motels, Resorts, Dormitories, & Correctional Facilities		cfm/room		L/s · room		See also food & beverage services, merchandising, barber & beauty shops, garages
Bedrooms (single, double)	5	30	15	15	7.5	Independent of room size
Living rooms (suites)	20	50	25	25	12.5	
Baths, toilets (attached to bedrooms)		50	50	25	25	Independent of room size; installed capacity for intermittent use.
		cfm/person		L/s · person		
Lobbies	30	15	5	7.5	2.5	
Conference rooms (small)	50	35	7	17.5	3.5	
Assembly rooms (large)	120	35	7	17.5	3.5	
Gambling Casinos	120	35	7	17.5	3.5	
Offices						
Office Space	7	20	5	10	2.5	
Meeting & waiting spaces	60	35	7	17.5	3.5	

TABLE D.6. (contd)

	Estimated occupancy, persons per 1000 ft^2 or 100 m^2 floor area. Use only when design occupancy is not known.	Outdoor Air Requirements				
		Smoking	Non-smoking	Smoking	Non-smoking	Comments
Public spaces		cfm/ft^2 floor		L/s · m^2 Floor		
Corridors & utility rooms		0.02	0.02	0.10	0.10	
		cfm/stall or urinal		L/s · stall or urinal		
Public restrooms	100	75	—	37.5	—	
		cfm/locker		L/s · locker		
Locker & dressing rooms	50	35	15	17.5	7.5	
Retail Stores		cfm/person		L/s · person		
Sales Floors & Showrooms						
Basement & Street floors	30	25	5	12.5	2.5	
Upper floors	20	25	5	12.5	2.5	
Storage Areas (serving sales & storerooms)	15	25	5	12.5	2.5	
Dressing rooms	—	25	5	12.5	3.5	
Malls & arcades	20	10	5	5	2.5	
Shipping & receiving areas	10	10	5	5	2.5	
Warehouses	5	10	5	5	2.5	
Elevators	—	—	15	—	7.5	
Smoking rooms	70	50	—	25	—	
Specialty Shops		cfm/person		L/s · person		
Barber & Beauty shops	25	35	20	17.5	10	
Reducing salons, health spas (exercise rooms)	20	—	15	—	7.5	
Florists	10	25	5	12.5	2.5	Ventilation to optimize plant growth may dictate requirements.
Greenhouses	1	—	5	—	2.5	
Show repair shops (combined workrooms/ trade areas)	10	15	10	7.5	5	
		cfm/ft^2 floor		L/s · m^2 floor		
Pet shops	—	1	1	5	5	
Sports & Amusement Facilities		cfm/person		L/s · person		
Ballrooms & Discos	100	35	7	17.5	3.5	
Bowling alleys (seating area)	70	35	7	17.5	3.5	When internal combustion engines are operated for maintenance of playing surfaces, increased ventilation rates will be required.
Playing floors (e.g., gymnasiums, ice arenas)	30	—	20	—	10	
Spectator areas	150	35	7	17.5	3.5	
Game rooms (e.g., cards & billiards rooms)	70	35	7	17.5	3.5	
Swimming pools		cfm/ft^2 area		L/s · m^2 area		
Pool & deck areas	—	—	0.5	—	2.5	Higher values may be required for humidity control.
		cfm/person		L/s · person		
Spectators area	70	35	7	17.5	3.5	

TABLE D.6. (contd)

	Estimated Occupancy, persons per 1000 ft^2 or 100 m^2 floor area. Use only when design occupancy is not known.	Outdoor Air Requirements				Comments
		Smoking	Non-smoking	Smoking	Non-smoking	
Theatres		cfm/person		L/s · person		
Ticket booths	—	20	5	10	2.5	
Lobbies, foyers, & lounges, & auditoriums in motion picture theatres, lecture, concert & opera halls	150	35	7	17.5	3.5	
Stages, TV & movie studios	70	—	10	—	5	Special ventilation will be needed to eliminate special stage effects (e.g. dry ice vapors, mists, etc.)
Transportation						
Waiting rooms, ticket & baggage areas, corridors & gate areas, platforms, concourses	150	35	7	17.5	3.5	Ventilation within vehicles will require special consideration.
Workrooms		Cfm/person		L/s · person		
Meat processing rooms	10	—	5	—	2.5	Spaces maintained at low temperatures (-10 F to +50 F, or -23°C to +10°C) are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining spaces is permissible. When the occupancy is intermittent, infiltration will normally exceed the ventilation requirement. (See Ref 21)
Pharmacists' workroom	20	—	7	—	3.5	
Bank vaults	10	—	5	—	2.5	
Photo studios						
Camera room, stages	10	—	5	—	2.5	
Darkrooms	10	—	20	—	10	
		cfm/ft^2 floor		L/s · m^2 floor		
Duplicating & printing rooms		—	0.5	—	2.5	Installed equipment must incorporate positive exhaust & control (as required) of undesirable contaminants (toxic or otherwise).
Educational Facilities		cfm/person		L/s · person		
Classrooms	50	25	5	12.5	2.5	
Laboratories	30	—	10	—	5	Special contaminant control systems may be required for processes or functions including laboratory animal occupancy.
Training shops	30	35	7	17.5	3.5	
Music rooms	50	35	7	17.5	3.5	
Libraries	20	—	5	—	2.5	

ventilation rates for the various buildings. Nevertheless, fresh air ventilation rates computed on the basis of ASHRAE Standard 62-1981 should be in the range of measured values for commercial buildings. Table D.7 compares measured and computed values. Measured values include data from both recent literature

TABLE D.7. Comparison of Computed and Measured Fresh Air Ventilation Rates

Building Category	Computed Ventilation Rate (ACH)	Measured Ventilation Rates (ACH)
Small Office	0.57	0.45 Building #3(a)
Medium Office	0.67	0.89 Building #1(a)
Large Office	0.41	2.2 Building #2(a)
Retail Store	0.97	--(b)
Strip Store	2.03	--(b)
Apartment	1.14	1.1 Low-rise with range 0.3 to 1.7(c)
		1.1 High-rise with range 0.9 to 1.4(c)
		0.5 High-rise with range 0.23 to 0.65 for winds calm to 14 mph(d)
		0.8 High-rise with range 0.1 to 1.17 for winds up to 35 mph(d)
Hotel	1.50	--(b)
Warehouse	0.25	0.1 to 0.2 Building #4(a)
Assembly	2.92	--(b)
School	0.77	0.3 Day Nursery(e)
		0.5 Kindergarten(e)

(a) Source: Appendix C.
(b) No publication found for this category.
(c) Source: Moschandreas et al. (1978).
(d) Source: Abu-Jarad and Fremlin (1982).
(e) Source: Lundquist et al. (1982).

and the case studies discussed in Appendix C. As Table D.7 shows, computed ventilation rates do reasonably represent measured values. This comparison indicates that the use of ventilation rates computed from ASHRAE Standard 62-1981 is a reasonable approach for building types that do not have literature-reported values.

D.6 COMPUTATIONS

For computing indoor pollutant concentrations, methods that met the requirements for this assessment were selected (e.g., methods that provide reasonable and comparable estimates of indoor air quality across generically different building categories and between the ASHRAE Standard 90A-1980 and proposed standard designs) without introducing unnecessary complicating factors. The computation methods described below are relatively simple; they are based primarily on the use of empirical emission factors that were derived from observations of indoor air quality as described in the literature. The use of these factors and the generic building characteristics, building usage, and ventilation rates provides a consistent method for assessing indoor air quality differences.

Although the computation methods selected are appropriate for indoor air quality comparisons in this assessment, these methods are not necessarily sufficient for evaluating buildings having special air quality problems that would require highly sophisticated models. In those cases, more detailed methods may be needed if information on building characteristics, air-handling equipment, emissions, and ambient outdoor concentrations is available. Examples of such models are EPA (1978) and EPRI (1981).

D.6.1 Computation of Indoor Radon Concentrations

Indoor radon concentrations are computed using

$$C = \frac{S + B + W}{V * I} + C_0 \qquad (D.3)$$

where

C = radon concentration, pCi/ℓ

S = soil emission rate, pCi/hr

B'= building emission rate, pCi/hr

W = water emission rate, pCi/hr

V = building volume (ℓ)

I = infiltration rate of outside air, total changes per hour

C_0 = ambient outdoor radon concentration, pCi/ℓ.

Radon emission rates in Table D.1 are used as typical values. To calculate concentration levels, building characteristics, water use, and soil emission rates must be considered. The radon's emission rate from soil into a building depends primarily on the characteristics of the foundation. Table D.1 shows an order-of-magnitude drop in the soil emanation rate into the building when the soil is covered by concrete. Ventilating the air between the soil and the building will also reduce the amount of radon entering the building. The general formula for computing soil emission rates into a building is:

$$S = F * R * G * 3600 \tag{D.4}$$

where

S = radon emission rate, pCi/hr

R = radon emanation rate, pCi/m^2/s (see Table D.1)

G = building base area, m^2

F = fractional air exchange between foundation and building.(a)

Building material emissions were computed based on flux per unit mass of material in the walls, floors, and ceiling. The general formula is:

$$B = p_f\ a_f\ t_f\ e_f + p_w\ a_w\ t_w\ e_w + p_c\ a_c\ t_c\ e_c \tag{D.5}$$

(a) F is unity (one) for buildings built slab-on-grade and with unvented crawl spaces. For buildings with basement or vented crawl spaces, F is less than 1. All commercial buildings were assumed to be built as slab-on-grade.

where

the subscripts f, w, and c refer to the total floor, walls and ceiling areas, respectively,

p = densities of building material

t = effective thickness of building material (1/2 actual value for exterior walls)

a = emission surface area

e = emanation rate.

No allowance was made for the positive building pressure that was assumed for the purpose of the analysis. Although no data were found to relate reduction of interior emissions with positive pressure, some reduction may occur, depending on the relationship between the source and air leakage factors.

Well water is the source of almost all of the water-derived radon. Radon levels are very low in surface water and the radon that is released from this source is small compared to that from soil and concrete. Emanation values given in Table D.1 are only guides for computing relative changes in indoor concentration levels. In actual measurements, the radon content of well water, for example, may range over many orders of magnitude. Thus, the release rates of radon from well water must be measured at the site to provide reasonably accurate estimates. The formula used for steady-state radon emission is:

$$W = R * U * E \tag{D.6}$$

where

R = a unitless constant (=0.6)

U = the water use per hour in the building

E = radon content of water (pCi/ℓ) (Table D.1).

Table D.8 contains typical water-use values for certain activities. The use values may then be combined with the occupancy rate to obtain estimates of U. For specific buildings, the usage per fixture may be used as an alternative computation approach.

Building volume is computed using the physical dimensions of the building's usable area. The ventilation rate of outside air, I, expressed in

TABLE D.8. Water-Use Activities and Fixture Rates in Public Buildings, Schools, and Camps

Water-Use Activity	Fixture Rate
Water-Use Fixtures	
Fill lavatory	2 gal
Fill bathtub	30 gal
Shower/bath	30-60 gal
Flush toilet	6 gal
Dishwasher	3 gal/load
Automatic laundry machine	30-50 gal/load
Lawn sprinkler	120 gph
1/2-in. hose and nozzle	240-300 gph
5/8-in. hose and nozzle	270-330 gph
3/4-in. hose and nozzle	300-360 gph
Public Buildings	
Hotel	50 gph per fixture
Apartment house	20 gph per fixture
Hospitals	25 gph per fixture
Office buildings	40 gph per fixture
Mercantile buildings	35 gph per fixture
1-1/2-in. fire hose and nozzle	2400 gph per fixture
Day school	50 gph per fixture
Schools and Camps	15-17 gph per fixture
Camp	40 gph per fixture
With hot and cold running water, kitchen, laundry, shower, bath and flush toilets	

Source: Golden et al. (1980).

complete air changes per hour, is needed as input to the calculation. Ground-level, outdoor ambient radon concentrations of 0.25 pCi/ℓ were used. To estimate indoor radon concentration values, the concentrations from each source are computed and added to an assumed background value.

D.6.2 Computation of Indoor Formaldehyde Concentrations

Continuous sources of formaldehyde were treated with a simple steady-state approach. Using the emanation rates presented in Table D.1, indoor formaldehyde concentrations may be estimated for the various sources with the equation:

$$C = \sum_{i=1,n} \frac{F_i M_i}{V * I} + \frac{W * A}{V * I} + \frac{E}{I} + C_o \tag{D.7}$$

where

C = formaldehyde concentration, $\mu g/m^3$

F_i = emission factor for building or furnishing material i, $\mu g/kg/hr$

M_i = mass of building or furnishing material i, kg

W = wall and ceiling insulation emission rate, $\mu g/m^2/hr$

A = wall and ceiling area, m^2

E = the sum of formaldehyde concentrations from smoking and gas stoves, $\mu g/m^3/hr$

V = the volume of the building, m^3.

I = the infiltration rate of outside air, total changes per hour

C_o = ambient outdoor formaldehyde concentrations, $\mu g/m^3$.

Formaldehyde emissions from the area of carpet specified for the test buildings were included as one of the sources (building furnishings).

The amount of formaldehyde released from insulation is highly variable. Although urea-formaldehyde foam is generally not used in new commercial buildings, formaldehyde and organic emissions from other types of insulation and building materials have been documented (Gupta, Ulsamer and Preuss 1982, p. 350; Molhave 1982, p. 117). New building materials have a higher total organics emission rate because of the effect of aging on the release rates of these pollutants (Miksch, Hollowell and Schmidt 1982, p. 132).

The following relationship provides a typical emission from the insulation:

$$W = S_W \times A \tag{D.8}$$

where

S_W = the emission rate per area of wall

A = the total insulation wall area computed from the dimensions of the buildings.

Unlike the first two steady state categories above (building materials and insulation), the following steady-state relationship was derived from intermittent releases of formaldehyde from combustion:

$$E_i = C_s * I_o + C_g * I_o \tag{D.9}$$

where

C_s and C_g = the computed air concentrations from smoking and an unvented gas stove for a specific building at an air-exchange rate of I_o.

As discussed above, ambient formaldehyde concentrations are very small, and C_o was set equal to zero. After each emission rate has been computed, modeled formaldehyde concentrations for different ACH rates may be computed.

D.6.3 Computation of Daily Average Combustion Product Concentrations

To estimate contributions of the various combustion pollutants from combustion sources, the following equation should be used:

$$\text{Average Daily Concentration} = \frac{(\dot{M}t_1)}{24\text{ hr} * I * V} + C_o \tag{D.10}$$

where

M = the constant source term emission rate (e.g., mg/hr)
t = the duration of that source term (hr)
I = the air-infiltration rate (total air changes/hr)
V = the building volume in m^3
C_0 = ambient concentration in supply air.

The ambient concentration in the supply air was assumed to be zero, based on the ASHRAE code stipulation that outside air must be cleaned if ambient pollutants exceed outdoor air quality standards. In reality, the fraction of air pollutants introduced into the building may vary. The computed numbers should be adjusted upward for buildings located in areas where significant concentrations of a pollutant will be in the supply air (assuming it is not filtered as it is drawn into the ventilation system).

D.7 AIR QUALITY COMPUTATION COMPARISON

The monitoring efforts described in Appendix C were used to provide case studies in which measured pollutant concentrations could be compared to the levels predicted by the model when monitored building parameters were used as inputs. In this way, the air quality computations derived from the model used in this analysis could be checked with case study information from actual buildings.

The air quality model was used to compute the indoor concentrations of radon, particulates, carbon monoxide, and formaldehyde for four commercial buildings that had been monitored for several days (Appendix C). Although the monitoring period was short, these studies made it possible to check the ability of the computational model to use specific inputs of building dimensions, materials, fresh air exchange rates, and building usage information to predict indoor air pollutant concentrations.

A zero background value was used when the measurement of a particular pollutant was either lacking or below the detection limit of instrumentation. The measured ACH for the sixth floor of Building #2 was not used because of a question about incomplete mixing of the SF6 tracer; this problem did not occur for the ground floor measurements or in the other buildings.

Table D.9 lists both short-term measured values (for work days with the HVAC system operating) and air quality values computed using building information and the indoor air quality model. In most cases where pollutants were detectable, the predicted and computed concentrations were of same order of magnitude. The monitored levels of radon and particulate concentrations were low in most cases, but were not totally incompatible with predicted values. For Building #3, no estimate of the fraction of smokers was available, so the default value of 0.333 was used. The measured particulate concentration was consistent with the minimum emission value. In Buildings #1 and #2, the fractions of smokers given in Appendix C were used. The measured particulates in Building #4 far exceeded the computed range for particulates. The difference was felt to be the result of emissions from the warehouse mechanical operations involving gas, diesel, and electric forklifts, which are not accounted for in the model used in this analysis.

TABLE D.9. Comparison of Measured and Computed Indoor Air Pollutant Concentrations

Building Number	Pollutant	Units	Monitored Values			Computed Values		
			Outdoor Concentration	ACH	Indoor Concentration	Min	Typical	Max
1	Radon	pCi/ℓ	n.m.(b)	0.89	0.33	0.05	0.9	1.0
	Particulate	$\mu g/m^3$	6.		24.	12.	24.	37.
	Carbon Monoxide	ppm	n.m.		n.m.	0.	0.	0.
	Formaldehyde	ppm	0.007		0.005	0.001	0.002	0.003
2 (sixth floor	Radon	pCi/ℓ	n.m.(b)	1.0(a)	0.12	0.00	0.02	0.20
	Particulate	$\mu g/m^3$	<10.(b)		17.	2.	7.	11.
	Carbon Monoxide	ppm	3.7		1.4	0.	0.	0.
	Formaldehyde	ppm	0.012		0.011	0.	0.001	0.001
2 (ground floor)	Radon	pCi/ℓ	n.m.(b)	1.7	0.07	0.02	0.04	0.51
	Particulate	$\mu g/m^3$	<5(b)		49.	2.	4.	7.
	Carbon Monoxide	ppm	2.7		2.	0.	0.	0.
	Formaldehyde	ppm	n.m.		0.011	0.	0.	0.001
3	Radon	pCi/ℓ	n.m.(b)	0.45	0.3	0.13	0.24	1.3
	Particulate	$\mu g/m^3$	13.		89.	106.	280.	490.
	Carbon Monoxide	ppm	5.3		4.5	0.	0.	0.
	Formaldehyde	ppm	0.001		0.002	0.009	0.026	0.044
4	Radon	pCi/ℓ	n.m.(b)	0.2	0.35	0.11	0.21	2.2
	Particulate	$\mu g/m^3$	16.		100.	18.	24.	26.
	Carbon Monoxide	ppm	4.		7.7	0.	0.	0.
	Formaldehyde	ppm	0.001		0.006	0.	0.001	0.001

(a) Estimated ACH for building.
(b) Zero background value used in computation.
n.m. = value not measured.

The modeled contribution of indoor carbon monoxide was less than 1 ppm in all buildings. The fact that the measured outdoor carbon monoxide concentrations consistently exceeded indoor concentrations in the first three buildings indicated that outdoor sources were the major source of indoor carbon monoxide in these buildings. In Building #4, there is an indication of an indoor source of carbon monoxide not accounted for by the model inputs; combustion products from forklifts are the likely source.

The measurements and computations of formaldehyde values confirm the low values expected in commercial buildings that have gone through an aging period (five years or more). These buildings do not have strong continuing sources related to activities in the building.

These comparisons demonstrate that the indoor air quality model used in this analysis predicted concentrations consistently with levels actually measured in commercial buildings. In this analysis common pollutant sources were used as a basis for comparing potential impacts between the ASHRAE Standard 90A-1980 design and the proposed standard design. Deviations from values predicted by the indoor air quality model in specific buildings related to special sources are to be expected and were seen in the monitored buildings. Nevertheless, the overall predictive ability of the model appears to be reasonably accurate.

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APPENDIX E

HEALTH EFFECTS OF SELECTED AIR POLLUTANTS

APPENDIX E

HEALTH EFFECTS OF SELECTED AIR POLLUTANTS

In this appendix the health effects of radon, organic pollutants, and benzo-[a]-pyrene are discussed. Radon and benzo-[a]-pyrene have carcinogenic effects, while formaldehyde and other organic pollutants may have carcinogenic effects.

E.1 RADON (RADON DAUGHTER)

Bale(a) and Harley (1953) were the first to note that the lung cancer hazard from exposure to radon and radon daughters was from the alpha dose delivered through lung deposition of the short-lived daughters of radon [^{218}Po(RaA), ^{214}Pb(RaB), ^{214}Bi(RaC) and ^{214}Po(RaC'] and not from the radon itself. Two alpha emitters, ^{218}Po(RaA) and ^{214}Po(RaC'), ultimately deliver the carcinogenic dose to tracheobronchial epithelium. The complexity in the dose estimates required to account for daughter deposition, radioactive buildup and decay, removal by physiological clearance processes, and physical dose calculations to specific cells in bronchial mucosa has been detailed by many authors and considered by various national and international organizations.

For more information on those authors' work, see Altshuler, Nelson and Kuschner 1964; Jacobi 1964, 1972, 1977; Haque 1966, 1967; Haque and Collinson 1967; Parker 1969; Walsh 1970, 1971, 1979; Harley and Pasternack 1972, 1981; Nelson et al. 1974; Fry 1977; McPherson 1979; Jacobi and Eisfeld 1980; James, Greenhalgh and Birchall 1980; James, Jacobi and Steinhausler 1981; Hofmann 1982; Wise 1982; United States Public Health Service (USPHS) 1957, 1961; Federal Radiation Council (FRC) 1967; Joint Committee on Atomic Energy (JCAE) 1967, 1969; International Commission on Radiological Protection (ICRP) 1977, 1981; United Nations Scientific Committee on the Effects of Atomic Radiation

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UNSCEAR) 1972, 1977; National Institute for Occupational Safety and Health/ National Institute of Environmental Health Sciences (NIOSH/NIEHS) 1971; and National Academy of Sciences (NAS) 1972, 1980.

Historically, exposure is defined in terms of the air concentration of radon daughters in units of working level (WL). A working level is defined to be a concentration of short-lived radon daughters (through RaC') totaling 1.3 x 10^5 MeV of potential alpha energy per liter of air. A working level month (WLM) is an equivalent exposure to 1 WL for 173 hours. These definitions avoid the problems of disequilibrium of the daughters and avoid the need to determine whether the daughters are attached to a carrier aerosol or remain unattached. Attached radon daughters deposit with some finite probability to the lung surfaces; unattached radon daughters deposit in the respiratory tract with virtual 100% probability. Thus, the mix of attached and unattached radon daughters is an important consideration in assessing lung dosimetry. The unattachment fraction values found in the workplace and in the environment are reasonably constant and not sufficiently different to cause a large disparity in the radiological dose assessment of environmental and occupational exposures to radon daughters. The same can be said for the other parameters influencing radon daughter lung dose such as differences in daughter product equilibrium, particle size distributions, breathing patterns, bronchial morphometry, and physiologic clearance processes.

E.1.1 Lung Dosimetry Models

The more recent lung dosimetry models for radon daughters are in substantial agreement with one another and place the bronchial epithelium exposure-to-dose conversion factor at about 0.5 rad/WLM for uranium miners. The dose per unit cumulative exposure has also been derived for environmental conditions (Harley and Pasternack 1981). Close agreement was found for the adult male (0.71 rad/WLM), adult female (0.64 rad/WLM), a 10-year-old child (1.2 rad/WLM), and a 1-year-old infant (0.64 rad/WLM). The small differences primarily reflect the reduced breathing rates during normal environmental exposures, lung morphometry, particle size differences, and the increased percentage of unattached RaA in ordinary atmospheres (~7% environmental versus ~4% in mines). These conversion factors indicate that a cumulative exposure in the environment is somewhat more effective in delivering a radiation dose than exposures under working conditions in a mine. Certain home energy conservation practices could produce exposure-to-dose conversion factors even closer to those calculated for the miners as a result of lower RaA unattachment fractions from any dustier home conditions. In some treatments of modeling of risk from radon daughter exposure, a tendency to artificially lower the cumulative exposure in the environment has been evident, presumably to account for decreased breathing rates under nonworking conditions (EPA 1982). This, in our opinion, is neither warranted nor justifiable in view of the uncertainties associated with the various rad/WLM values. The WL and WLM, therefore, are given equal weight in our treatment of risk, whether the exposure is environmental or occupational.

E.1.2 Radon Daughter Epidemiology Studies

The epidemiological data derived from many types of underground mining show a relatively consistent relationship between lung cancer incidence and exposure to radon daughters in WLM. This underlying consistency is probably related to the relatively narrow range of bronchial dose per WLM. Assessing the risk of attributable lung cancer through human epidemiological studies is difficult because the detailed information required is not available. In the ideal case, the exposure of each miner as a function of time would be long enough and the follow-up period would be long enough for all of the group to have died from lung cancer or other causes. In addition, separating attributable lung cancers from those arising spontaneously or from cigarette smoking would be possible. The cumulative exposure, person-years at risk, and the number of attributable lung cancers would allow the exact calculation of a risk factor.

The present data do not fulfill the above requirements because exposures are only estimates and the follow-up periods are not long enough. Nevertheless, by recognizing the limitations of the data, we can estimate a mean risk factor based on the available epidemiological data.

Human data are now available from several groups of underground metal ore miners: the U.S., Canadian, and Czechoslovakian uranium miners; Swedish and British iron miners; Swedish lead and zinc miners; and Newfoundland fluorspar miners. Although other potential carcinogens such as diesel smoke, traces of arsenic or nickel and iron ore are found in these mines, the lung cancer response appears to be predictably based on radon daughter exposure. Some of these studies have divided the workers into subgroups on the basis of exposure. Eighteen of these subgroups were selected (Archer, Radford and Axelson 1979) as being most suitable (considering both epidemiological and environmental data) for quantitative treatment of the lower exposure levels. In addition to this treatment, these mining populations have been reviewed by other authors and organizations (NIOSH/NIEHS 1971; NAS 1972, 1980; Sevc, Kunz and Placek 1976; Jorgensen 1973; Axelson and Sundell 1978; Snihs 1973, 1974; Renard 1974; DeVilliers and Windish 1964; Wright and Couves 1977; McCullough, Stocker and Makepeace 1979; UNSCEAR 1977; Evans et al. 1981; and Radford 1981a).

The data thus far suggest that an absolute threshold exposure for lung cancer induction is highly unlikely. This is consistent with current views of radiation biology and radiation protection, that radiation-induced cancer is a stochastic process. Some argue that the lung cancer mortality data at the lowest reported exposures are not statistically different from those expected (Evans 1967; Stranden 1980) and that at least a "practical" threshold for radon daughter carcinogenesis may exist. Archer, Radford and Axelson (1979) conclude from their analysis of the 18 subgroups that if a threshold exists, it is below 20 to 30 WLM. Snihs (1973, 1974) considers the lowest underground exposure resulting in an apparent increase in lung cancer deaths in Swedish miners to be about 15 WLM, although he states that drawing conclusions about the exposure-response relationship below 100 WLM is impossible. Hewitt (1979) concludes from the analysis of Canadian uranium miners that if a threshold exists, it is below 60 WLM. Thus, the possibility exists that ambient radon daughters from low-level outdoor and indoor sources do not induce lung cancer.

The incidence of lung cancer attributable to radon daughter exposure observed in the various mining subgroups ranges overall from about 1.5 to 50 cases per WLM/year/10^6 persons, with a reasonable average value of 10×10^{-6} per person per year per WLM. This average value has been accepted in the lung cancer estimation model of Harley and Pasternack (1981) as being reasonably realistic when predictive data are compared to background (normally occurring) lung cancer incidence in nonsmokers from environmental exposure to radon.

In estimating the effect of radon daughter exposure at environmental levels (normally less than about 20 WLM per lifetime), the attributable risk at high exposures must somehow be extrapolated to the low exposure region. With the conventional method, the extrapolation is linear, even though some studies suggest that exposures may be even more efficient in inducing lung cancer as the exposure rate approaches background levels (Archer 1978).

E.1.3 Influence of Cigarette Smoke

The effect of cigarette smoke on radiation-induced cancer probabilities is still unresolved. During periods of relatively short follow-up (15 to 25 years), cigarette smoking is associated with a markedly increased incidence of lung cancer in miners. During periods of follow-up that are 30 to 60 years after initial exposure, lung cancer incidence is reported to be either somewhat greater among nonsmokers than smokers (Axelson and Edding 1980) or about the same (Radford 1981b). The human evidence has been confirmed in studies with beagle dogs; in those studies, dogs that smoked had fewer respiratory tract tumors than dogs that did not smoke, but they had comparable radon daughter exposures (Cross et al. 1978). The data on cigarette smoking suggest that smoking's principal role in lung cancer among uranium miners is to accelerate the appearance of cancers induced by radiation. The role of smoking at reduced radon levels is unknown.

E.1.4 Animal Studies

Animal studies were conducted several decades ago in initial attempts to identify the nature and levels of uranium mine air contaminants that were responsible for producing the lung cancers observed among uranium mining populations. Many of these studies were concerned with early effects or short-term pathologic changes (Jansen and Schultzer 1926; Read and Mottram 1939; Jackson 1940). In these studies also, exposures were primarily based on radon gas concentrations, thus leaving little or no information on the radon daughter concentrations that subsequently have been shown to contribute the greatest radiation dose to the lung. The earlier studies in which lung tumors were produced were methodologically or statistically inadequate to show an unequivocal association of lung tumors after exposure to radon or radon daughters (Huech 1939; Rajewsky, Shraub and Shraub 1942a, 1942b; Kushneva 1959).

Beginning in the 1950s, a growing concern emerged that the increased incidence of respiratory cancer observed in the European uranium mining population would also be found in the U.S. mining population (Seven State Uranium Mining Conference 1955; Wagoner et al. 1964). Systematic studies were subsequently begun in this country to identify the agents responsible for the excess lung cancer and to develop exposure-response relationships with animals. The importance of accurately determining the levels of radon daughter radionuclides in mine air was also noted by several investigators (Bale and Shapiro 1956; Harley 1953). Researchers at the University of Rochester began to focus attention on the biological and physical behavior of radon daughters as well as their contribution to the radiation dose of the respiratory tract (Bale 1951; Harris 1954; Morken 1955). Shapiro (1954) exposed rats and dogs to several levels of radon alone and in the presence of radon daughters attached to "room dust" aerosols. He showed that the degree of attachment of radon daughters to carrier dust particles was a primary factor influencing the radiation dose to the airway epithelium and demonstrated that this dose was due primarily (>95) to the short-lived radon daughters RaA (^{218}Po) and RaC' (^{214}Po), rather than to the parent radon.

Cohn, Skow and Gong (1953) reported relative levels of radioactivity found in the nasal passages, trachea plus major bronchi, and the remainder of rat lungs after exposure to radon and radon daughter products. The respiratory tracts of animals that inhaled radon plus its decay products contained 125 times more activity compared with those of animals that inhaled radon alone.

Beginning in the mid 1950s, Morken initiated a pioneering series of experiments to evaluate the biological effects of inhaled radon and radon daughters in mice, with later experiments using rats, as well as beagle dogs (Morken and Scott 1966; Morken 1973a, 1973b). The essentially negative character of the biological results shown in these studies suggested that α-irradiation is inefficient in producing radiation-specific tumors in the respiratory system. The only apparent late and permanent changes occurred in the alveolar and respiratory bronchial regions of the lung for a wide range of exposure levels and for observation times of three years in the dog and one and two years in the rat and mouse. Injury was produced in the bronchial tissue, but it was quickly repaired after irradiation ceased.

In the late 1960s and early 1970s, France and the U.S. initiated studies in which lung tumors were successfully produced from inhaled radon daughters (Perraud et al. 1970; Chameaud et al. 1974, 1980; Cross et al. 1978). At an average estimated lung dose of about 3000 rad from radon daughters, following prior lung stressing with stable cerium, several of the rats in the French studies developed malignant tumors (Perraud et al. 1970). In subsequent French studies, rats exposed either to radon daughters alone or in combination with uranium ore dust and cigarette smoke also produced tumors in the lung (Chameaud et al. 1974, 1980). The U.S. studies were designed to systematically determine the pathogenic role of radon daughters, uranium ore dust, diesel engine exhaust fumes, and cigarette smoke, alone or in various combinations. These studies involved life-span exposures of beagle dogs and Syrian golden hamsters (Cross et al. 1978). Follow-up studies are currently being conducted with rats. In the later U.S. studies, tumors also were produced in the respiratory tracts of the animals.

The animal studies have supported the human epidemiology studies. Noted similarities are as follows:

1. Tumor production per WLM at very high exposures is lower than at moderate exposures. This has been tested primarily in rats (Cross et al. 1980; Chameaud et al. 1980). The lowest attributable lung cancer rates per unit exposure were observed in the U.S. uranium miners and Canadian fluorspar miners, where radon daughter levels were the highest of all the underground mines.

2. Tumor production appears to increase with a decrease in exposure rate (Cross et al. 1980). This is suggested in both the human and animal studies although exposure rate is considered to be of less importance than cumulative exposure.

3. A lower lifetime incidence of lung cancer is observed in dogs exposed to cigarette smoke in succession with radon daughters and uranium ore dust than to radon daughters and uranium ore dust without cigarette smoke (Cross et al. 1978). This effect was also observed in a small group of Swedish zinc-lead miners and is tentatively ascribed to the protective effect of increased mucus production from smoking (Axelson and Sundell 1978) or of the thickened mucosa resulting from smoker's bronchitis. Tobacco smoke has been found to be cocarcinogenic with radon daughters when given to rats following their cumulative exposure to the daughters (Chameaud et al. 1980). This effect is not observed, however, when smoking precedes the radon daughters (Chameaud et al. 1981). This may partially explain the discrepancies observed in the interpretation of epidemiological data.

4. Emphysema can be attributed to radon daughter exposure in both animals (hamsters, rats, and dogs) and underground miners. The simultaneous presence of ore dust or diesel fumes does not appear to increase the number of tumors produced by exposure to radon daughters (Cross et al. 1978, 1980; Chameaud et al. 1981).

5. For equal cumulative exposures, the older the age at the start of exposure, the shorter the latency period and, within limits, the higher the associated risk. In humans, the highest risk coefficient calculated, 50 x 10^{-6} lung cancers per year per WLM, is for persons first exposed later in life (over 40 years of age) (Chameaud et al. 1981).

6. The estimates made by the various dosimetric models appear to be borne out in the various species. The tumors induced in experiments with hamsters and rats, which have similar lung morphometry, occur in the distal portion of the conducting airways or in the pulmonary region. Based on calculations, these regions receive the highest

dose (Desrosiers, Kennedy and Little 1978). Human tumors appear almost exclusively in the upper generations of the bronchial tree. Absorbed dose calculations show that basal cells in the upper airways at about the segmental bronchi receive the highest dose from radon daughters (Harley and Pasternack 1972).

7. Lifetime risk coefficients are similar in both the animals and humans. The rat data appear to range between 1 and 4 x 10^{-4} per WLM for all tumors (benign and malignant) at cumulative exposures less than 5000 WLM (Chameaud et al. 1981).(a) At exposures where life-span does not appear to be significantly shortened (<500 WLM), the lifetime risk coefficient appears to be about 2 x 10^{-4} per WLM for malignancies and ranges between 2 to 4 x 10^{-4} for all tumors. There is, as yet, insufficient data to determine the value below 100 WLM exposures.

E.2 ORGANIC POLLUTANTS

The discussion in this section is divided into two parts. Formaldehyde is discussed separately from the other organics because more information is available on formaldehyde than any other organic pollutant.

E.2.1 Organics Other Than Formaldehyde

The air inside commercial buildings can contain an extremely wide variety of organic substances of several general types. Included are pesticides, paints, solvents, building materials, and several other substances containing an extremely broad array of potentially harmful chemicals (Ulsamer, Gupta and Kang 1981; Molhave 1982; Miksch, Hollowell and Schmidt 1982). The diversity of these substances and their roles as indoor air pollutants have been reviewed recently (National Research Council 1981; Miksch, Hollowell and Schmidt 1982). Many of the substances are associated with specific human and commercial activities. Therefore, it is not possible to generically describe the anticipated

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(a) Also, F. T. Cross, et al. Unpublished data from draft report, An Overview of the PNL Experiments With Reference to Epidemiology Data. Pacific Northwest Laboratory, Richland, Washington.

levels of these substances, or the potential health health risks associated with exposure, in order to estimate effects on the health of the general population.

Little research has been done to identify or measure organic substances, other than formaldehyde, that may be harmful indoor air pollutants (National Research Council 1981). In most instances the concentrations of specific organic compounds in non-industrial indoor environments are below OSHA-established limits. Any health hazard associated with exposures at these levels cannot be assessed (National Research Council 1981). It is possible, however, that cumulative exposure to compounds at low concentrations, or synergistic effects among substances, may be related to symptomatic complaints by building occupants. Such substances may explain complaints of symptoms of respiratory irritation and/or malaise in indoor environments where formaldehyde or other indoor pollutants are not implicated (Molhave 1979).

Molhave (1982) has recently examined organic gases and vapors emitted by solvents contained in common building materials. He identified 52 different organic gases and vapors of solvent type in the air around 42 different building materials. It is not possible to determine the health risks of these compounds, but Molhave (1982) notes that no compound was measured in concentrations exceeding their Danish threshold limit value. Of the 52 compounds, 82% are known or suspected irritating compounds, 25% are suspected carcinogens, and 30% have an odor threshold below the average concentration measured in this study.

Although the health risks associated with organic substances from building materials cannot be clearly established, it is unlikely that the change in levels associated with the proposed programs will have an adverse effect on the health of the exposed populations. For example, Miksch, Hollowell and Schmidt (1982) found that the concentrations of individual organic contaminants in offices were lower by 2 to 4 orders of magnitude than the levels recommended for protecting the health of workers in the industrial setting. Thus, the data from Molhave (1982), combined with those from Miksch, Hollowell and Schmidt

(1982), suggest that although a health hazard associated with indoor air pollution by organic substances is possible, the risks of such health effects are low and cannot be estimated at present.

E.2.2 Formaldehyde

Much of the current concern about health effects of formaldehyde exposure relates to evidence suggesting that it is a carcinogen. Studies carried out by the Chemical Industry Institute of Toxicology (CIIT) found an excess of squamous cell carcinoma of the nasal turbinates in rats and mice exposed to 15 parts per million (ppm) of formaldehyde vapor (Swenberg et al. 1980). Subsequent studies demonstrated carcinomas in rats at exposure levels of 6 ppm (CIIT 1981).

Animal studies and limited human epidemiologic studies relating to the carcinogenicity of formaldehyde have been reviewed by the Federal Panel on Formaldehyde (Griesemer 1982). On the basis of their review, the panel concluded that it is prudent to regard formaldehyde as posing a carcinogenic risk to humans (Griesemer 1982). A similar conclusion was reached by Selikoff and Hammond (1981).

Differences of opinion exist on the human epidemiologic data. For example, Bryson (1981) stated that in four retrospective studies (presented at a 1980 CIIT seminar on formaldehyde), of the people engaged in the manufacture and use of formaldehyde, no overall excess of deaths from cancer or from respiratory disease were reported. Infante et al. (1981), in rebutting Bryson's communication, noted that excess mortality was observed for some cancer sites in two of those studies. It was their opinion, because of limitations in study design and methodology, that "the studies do not provide any definitive evidence upon which to evaluate the carcinogenicity of formaldehyde to man" (Infante et al. 1981).

E.3 BENZO-[a]-PYRENE

Evidence of the ability of benzo-[a]-pyrene (BaP) to cause cancer comes both from animal studies and from human epidemiologic studies. Animal studies have demonstrated the carcinogenicity of BaP in several species and through several routes of exposure.

The best evidence for the carcinogenicity of BaP in humans comes from epidemiologic studies of workers who have been exposed to this substance in their occupations. Several types of cancers have been found to be increased among such workers. This includes cancer of the scrotum among chimney sweeps, the classic occupational cancer described by Percival Pott in the 18th Century, increased rates of lung cancer in roofing tar applicators (Hammond et al. 1976) and British gas-retort workers (Doll 1952), and increased rates of cancer of the lung and other organs in workers exposed to the emissions from coke ovens (Redmond, Strobino and Cypess 1976).

In addition to the studies of workers, several investigators have suggested relationships between levels of BaP in outdoor air and lung cancer rates. These studies include correlation of lung cancer mortality rates in urban and rural populations with BaP levels (Carnow and Meier 1973), higher rates of lung cancer in areas of cities where BaP levels are high (Menck, Casagrande, and Henderson 1974), and other correlative studies (Pike et al. 1975). Studies of this type, which are based on correlating population rates and air pollution data, do not prove a cause-effect relationship. They do, however, provide additional suggestions regarding the health effects of exposures to hazardous substances.

Finally, BaP is an important component of cigarette smoke (National Research Council 1981). Whereas the entire carcinogenicity of cigarettes cannot be attributed to BaP, its contribution should not be overlooked (Santodonato, Howard and Basu 1981). Cigarette smoke is a major contributor to indoor BaP levels.

Recently, the Environmental Protection Agency (EPA) developed estimates of cancer risk for populations exposed to coke oven emissions (EPA 1981). The EPA discusses exposure to what is referred to as the benzene soluble organic (BSO) fraction of emissions, of which BaP is a component. They derived a unit risk factor, the lifetime probability of dying from lung cancer as a result of coke-oven emissions, as indicated by a measure of BSO per cubic meter of ambient air. This measure was obtained by taking the dose-response relationship known from studies of lung cancer among coke-oven workers and estimating what the rate of lung cancer would be with lower levels of exposure to the general population. The measure is based on an approach to risk estimation that assumes there is no level of exposure that does not have some--however slight--increase in risk associated with it. The estimated lifetime risk of dying from lung cancer is 9.25 x 10^{-4} if a person is exposed continuously to 1 μg of BSO from coke ovens per cubic meter of air. This risk estimate could, with great caution, be used to estimate risks associated with BaP exposure.

Pike and Henderson (1981) have recently developed risk estimates for lung cancer associated with BaP air pollution. Table E.1 shows the relative risk for lung cancer in never-smokers at various levels of BaP. Table E.2 shows the cumulative lifetime lung cancer incidence (mortality) projected for various levels of BaP exposure. These risk estimates are based on a model developed from the risk of lung cancer among cigarette smokers and tested using data from occupational populations exposed to BaP. Because these estimates are specific to BaP, they were used in preference to the EPA estimates based on BSO. The EPA estimates were included in the discussion, however, because they are developed from the most thoroughly studied occupational population, the coke-oven workers.

TABLE E.1. Relative Risk of Lung Cancer in Never-Smokers at Various Levels of BaP Air Pollution (Pike and Henderson 1981)

BaP Level (ng/m^3)	Relative Risk
0	1.00
0.4	1.07
1	1.17
2	1.33
5	1.83
6	2.00
10	2.67

TABLE E.2. Calculated Lifetime Lung Cancer Incidence Among Never-Smokers at Various Levels of BaP Air Pollution (Pike and Henderson 1981)

BaP Level (ng/m^3)	Cumulative Incidence Rate/100,000
0.014	1
0.1	7
1	73
5	363
10	724
20	1443

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APPENDIX F

AGENCIES AND PERSONS CONTACTED

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