Conf-9108109--3

PNL-SA--19657

DE92 000392

ENVIRONMENTAL ISSUES IN PLANNING BUILDING ENERGY TECHNOLOGIES R & D IN THE UNITED STATES

A. K. Nicholls
B. C. Farhar
J. P. Millhone
F. H. Abel

August 1991

Presented at the
International Symposium on Energy and Environment 1991
August 25-28, 1991
Espoo, Finland

Work supported by
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

ENVIRONMENTAL ISSUES IN PLANNING BUILDING ENERGY TECHNOLOGIES R&D IN THE UNITED STATES

Barbara C. Farhar, Ph.D.
Fred H. Abel, Ph.D.
Andrew K. Nicholls
John P. Millhone

ABSTRACT

The U.S. Department of Energy's Office of Building Technologies (OBT) has begun studies on the relationship and impact of buildings energy use on the environment, particularly with respect to global climate change, acid rain, stratospheric ozone depletion, and indoor air quality. The paper presents an overview of international and U.S. federal activity in global change to set OBT's activities in context. The paper then reviews briefly the contribution of buildings to atmospheric problems through building energy use. OBT's program primarily supports projects with indirect environmental impacts through energy efficiency (e.g., thermally activated heat pumps use natural gas instead of electricity) and the use of renewables in buildings. The paper briefly describes the OBT program and covers an inventory of projects that OBT has funded on environmental/building problems. Analyses have included three kinds of topics: (1) CFC substitutes for refrigeration equipment, (2) incorporating the cost of externalities into utility electricity generation, and (3) indoor air quality. The paper shows how environmental issues are being taken into account in planning the U.S.'s R&D program in building energy technologies.

Abstract[1]

The U.S. Department of Energy's (DOE's) Office of Building Technologies (OBT) has begun studies on the relationship and impact of buildings energy use on the environment, particularly with respect to global climate change, acid rain, stratospheric ozone depletion, and indoor air quality. The paper presents an overview of international and U.S. federal activity in global change to set OBT's activities in context. The paper then reviews briefly the contribution of buildings to atmospheric problems through building energy use. OBT's program primarily supports projects with indirect environmental impacts through energy efficiency (e.g., thermally activated heat pumps use natural gas instead of electricity) and the use of renewable energy technologies (RETs) in buildings. The paper briefly describes the OBT program and covers an inventory of projects that OBT has funded on environmental/building problems. Analyses have included three kinds of topics: (1) CFC substitutes for refrigeration equipment, (2) incorporating the cost of externalities into utility electricity generation, and (3) indoor air quality. The paper shows how environmental issues are being taken into account in planning the U.S.'s R&D program in building energy technologies.

The International Context

A number of international organizations have involved themselves in global change research. The U.S. government coordinates its global research planning with efforts in other countries. The World Meteorological Organization (WMO) and the United Nations Environment Program established the Intergovernmental Panel on Climate Change (IPCC)

---

[1]Barbara C. Farhar is senior social scientist, Solar Energy Research Institute; Fred H. Abel is senior economist, U.S. Department of Energy; Andrew K. Nicholls is research economist, Pacific Northwest Laboratory; and John P. Millhone is deputy assistant secretary, Office of Building Technologies, U.S. Department of Energy; all in Washington, D.C.

in 1988. In addition, the International Council for Scientific Unions (ICSU) established the International Geosphere-Biosphere Program (IGBP) in 1986. The IGBP plan of action focuses on (1) terrestrial biosphere-atmosphere interactions, (2) marine biosphere-atmosphere interactions, (3) biospheric aspects of the hydrological cycle, and (4) effects of climate on terrestrial ecosystems (Price 1990). The International Energy Agency (IEA) has sponsored a study on Energy Efficiency and its Contribution to Environmental Goals (McNutt 1990). Among other international organizations with global change research programs are the International Social Science Council (ISSC), the International Federation of Institutes of Advanced Study (IFIAS), the United Nations University (UNU), the European Science Foundation, and the Latin American Social Science Council (Miller 1990).

The IPCC has focused significant international cooperation in defining response to global change. One of the Panel's tasks was to formulate response strategies to global climate change. In its 1991 report (IPCC 1991: xxv), the IPCC stated, "We are certain emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases . . . [and that] these increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface . . . . The long-lived gases would require immediate reductions in emissions from human activities of over 60 percent to stabilize their concentrations at today's levels."

The Panel found that most emissions originate in industrialized nations. It recommended that these nations consider integrated "limitation and adaptation" strategies to lessen the costs of responding to climate change. In the short term, the IPCC recommended such limitation actions as improved energy efficiency, use of cleaner energy sources and technologies, and phasing out of CFCs under the Montreal Protocol. In the

longer term, the IPCC recommended the development of new energy technologies (IPCC 1991:xxvii).

The U.S. Domestic Context for Buildings Research

Nine agencies of the U.S. federal government participate in the U.S. Global Change Research Program (USGCRP). The interagency Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology coordinates this program. The USGCRP's goal is to establish the scientific basis for national and international policy on global change (Office of Science and Technology Policy 1991).

CEES has established "science priorities" or "integrating themes" in the study of global change; these are, in order of priority: (1) climate and hydrologic systems, (2) biogeochemical dynamics, (3) ecological systems and dynamics, (4) earth system history, (5) human interactions, (6) solid earth processes, and (7) solar influences.

Table 1 shows the anticipated FY 1992 funding for these integrating themes by federal agency.

DOE's proposed $77 million global change research budget, a 17.4% increase above FY 1991 levels, is directed at the impact of energy production and use on the global earth system. DOE has roles in many aspects of the USGCRP, such as in atmospheric composition and global ocean circulation. As part of this national research program, DOE undertakes research areas of relevance to buildings energy use. For example, DOE and EPA will be supporting research on anthropogenic emissions sources, including industrial and technological consumption of fossil fuels. DOE will predict future consumption using different technologies. With other agencies, DOE will gather data on population size, distribution, and human factors in natural resources use and production of emissions.

Table 1. Anticipated FY 1992 Funding for Global Change Research by Agency
($ in millions)

Agency	Total Budget	Pre-diction	Water/ Energy Cycles	Global Carbon Cycle	Ecol. & Pop. Dynamics	Other
Totals	1185.5	95.4	521.2	162.8	146.9	259.2
NASA	772.6	27.9	377.7	70.5	72.1	224.4
NSF	118.5	10.4	39.0	30.1	19.4	19.6
NOAA	78.0	20.2	44.1	7.2	2.4	4.1
DOE	77.0	26.5	32.0	18.5	0	0
USDA	53.2	5.5	2.8	14.5	26.1	4.3
DOI	46.4	4.9	20.7	5.0	14.0	1.8
EPA	26.0	0	0	14.8	7.4	3.8
SI	7.5	0	0.1	1.9	4.5	1.0
DOD	6.3	0	4.8	0.3	1.0	0.2

Legend: National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Energy (DOE), U.S. Department of Agriculture (USDA), U.S. Department of the Interior (DOI), Environmental Protection Agency (EPA), Smithsonian Institution (SI), U.S. Department of Defense (DOD).

Source: Office of Science and Technology Policy 1991:19.

Note: "Other" includes human interactions, solid earth processes, and solar influences.

CEES identified a lack of knowledge about the specific processes by which individual and institutions interact with the environment. DOE, along with NSF, EPA, and USDA, may be funded in the future to investigate direct human action and indirect social, structural, and institutional influences on global change. DOE may also study technology transfer and diffusion processes and play a role in scientific and public education (Office of Science and Technology Policy 1991). For example, DOE's Information/Coordination Program will improve the Carbon Dioxide Information Analysis Center.

In addition, the National Energy Strategy (NES), issued in February 1991, calls for

In addition, the National Energy Strategy (NES), issued in February 1991, calls for an understanding of total fuel cycle costs, including effects on the global environment. For example, NES measures are expected to reduce SO_2 emissions by 12 million tons and NO_x emissions by 5 million tons in 2010 (U.S. Department of Energy 1991a).

Besides DOE's Global Change Research funding, the U.S. government allocates additional resources to DOE's Office of Conservation and Renewable Energy's (CE's) program. The CE program covers transportation, utility, buildings, and industrial energy sectors, as well as technical and financial assistance. The CE role in energy efficiency and RETs, including buildings technologies, complements the funding directly assigned to global change research. To the extent that it is generated by fossil fuels, energy used in buildings contributes to atmospheric environmental problems.[2]

The Contribution of U.S. Buildings to Atmospheric Global Change

Energy use in U.S. residential and commercial buildings contributes significantly to emissions of carbon dioxide (CO_2), a major determinant of the greenhouse effect, and of sulfur dioxide (SO_2) and nitrogen oxide (NO_x), the principal precursors of acid rain. NO_x has also been identified as a greenhouse gas and contributes to ozone formation in cities.

These three emissions are formed when fossil fuels are combusted to provide energy, but not all fossil fuels are equally pernicious. As a general guideline, natural gas is relatively clean and coal relatively "dirty," with oil in between, but much closer to coal. For example, per unit of energy consumed, coal yields 73% more CO_2 emissions than natural

---

[2]Utilities supply much of the energy used in buildings. CE's Office of Utility Technologies also pursues a vigorous program to develop the use of renewable energy technologies on the supply side. These efforts can be expected to have positive environmental consequences as well. A full exploration of these consequences is beyond the purview of this paper.

gas and 24% more than oil (Edmonds et al. 1989). For SO_2, coal use produces over 90% of total U.S. emissions, while natural gas use virtually produces none.

Chlorofluorocarbons (CFCs) are a class of industrial chemicals that deplete the stratospheric ozone layer leading to possible higher incidences of skin cancer and genetic damage to living organisms. In addition, they contribute to global climate change. In 1986, the United States produced and consumed 333,844 metric tons of CFCs, roughly 30% of the global total (U.S. Department of Energy 1989a). Nearly 60% of U.S. total production was for energy-related applications. Buildings are significant consumers of CFC-11 and CFC-12, the most significant CFCs in the United States, together constituting 70% of total U.S. CFC usage of Protocol-regulated chemicals in 1986. In buildings, CFC-11 and CFC-12 are employed as the refrigerant in refrigerators, freezers, chillers, and air conditioners. They are also used in the foam used to insulate building envelopes, refrigerators, and freezers. In 1985, buildings were responsible for more than three-quarters of the energy-related usage of CFC-11 and about half of the energy-related usage of CFC-12 (Statt 1988).

Since the United States is a significant consumer of coal, petroleum, and natural gas, and since buildings consumed about 35% of the U.S. primary energy total in 1987, it is not surprising that energy use in buildings is a significant source of anthropogenic emissions of CO_2, SO_2, and NO_x. The emissions from buildings energy use can be usefully characterized as arising from two distinct sources. First, emissions are generated directly when wood and fossil fuels, principally natural gas and oil, are burned at the building site to provide energy services such as space heating, cooking, and water heating. Second, emissions are produced "indirectly" by the wide use of electricity in buildings, since the electricity used to power lights, electric furnaces, air conditioners, and appliances is largely generated with fossil fuels. As a source of emissions, the use of electricity in U.S. buildings is considerably more

important than the site use of fossil fuels. This is easily explained: in 1987, more than 60% of total buildings primary energy use was in the form of electricity and 55% of that electricity was generated with coal (U.S. Department of Energy 1989b). This picture is expected to become more acute in the future, according to the Reference Case of the NES analysis. This Reference Case was used as a baseline against which the impact of various technological options on energy use was assessed. The Reference Case was defined as one in which no new U.S. policies are enacted. The NES Reference Case projected increasing electrification of buildings and increasing use of coal to produce electricity.

The National Energy Strategy Reference Case provides historical U.S. emissions of CO_2, SO_2, and NO_x, as well as projections to the year 2030 based on projected energy use patterns (U.S. Government Printing Office 1991). The Reference Case assumed that building energy use accounted for about 480 million metric tons of carbon per year in 1987, nearly 40% of the U.S. total. Since the United States is now responsible for about one-quarter of total global emissions (Edmonds et al. 1989), U.S. buildings are therefore accountable for nearly 10% of the global total. The Reference Case projected that by 2030, buildings emissions will have climbed to about 1000 million metric tons of carbon per year, although the share of the U.S. total remains identical to the share in 1987.

The Reference Case also indicated that in 1987, the buildings sector released 10.2 million metric tons of SO_2 and about five million metric tons of NO_2, primarily from fossil-fired electricity use. These amounts are, respectively, 48% and 31% of the U.S. anthropogenic totals. By 2030, the Reference Case projections indicate that U.S. buildings will emit 9.2 million metric tons of SO_2 and 6.9 million metric tons of NO_2, 37% and 31% of the respective U.S. totals.

In 1987, the United States signed the Montreal Protocol, an agreement to reduce production of CFCs by 50% by 1998. Subsequently, President Bush announced support for an expansion of the Protocol to phase out production of CFCs by 2000, provided safe substitutes are available. DOE is pursuing research into identification of substitutes for CFCs to help the United States fulfill its Montreal Protocol commitments.

The Office of Building Technologies (OBT) Program

OBT's goal is to lead a national effort to meet the needs for building energy services through increased energy efficiency and the use of RETs (U.S. Department of Energy 1991b). If actualized in practice, this goal means no future increase from 1990 levels in nonrenewable energy consumed in buildings. In the United States, buildings used approximately 29 quads of energy in 1988, an increase of 1.4 quads from 1987. This increase reversed an earlier trend toward improved efficiency in buildings.

OBT has designed its program to achieve two aims: (1) developing energy efficiency and solar technologies by 2000 that use only 75% of the energy of current best-available technologies and (2) increasing the adoption rate of advanced technologies. Among several assumptions undergirding the program are that (1) environmental and health concerns about indoor air quality will grow in importance, and (2) acceptable CFC alternatives must be found for refrigerants and foaming agents for insulation.

The program consists of 10 key activities; these are, in order of priority, as follows.

1. Program direction (staff and support services).

2. Building systems research. Computer-based tools for commercial buildings, industrialized housing, building standards, and building retrofit.

3. Lighting and appliances. Research on high efficiency lighting, advanced refrigeration, and appliance/lighting standards.

4. Federal Energy Management Program. Technical, management, and financial assistance to federal agencies for improving energy efficiency in their facilities.

5. Solar technologies. Research on solar space/water heating, space cooling and dehumidification, and daylighting.

6. Implementation and deployment. Dissemination of technical information.

7. Evaluation and planning. Data collection, technology assessment, and program planning and evaluation.

8. Materials and structures. R&D on improved insulation materials and energy efficiency in building envelope components; i.e., walls, roofs, windows, and foundations.

9. Heating and cooling equipment. R&D on thermally activated heat pumps, improved oil combustion technology, advanced/non-CFC refrigeration systems, and thermal distribution and control systems.

10. Indoor air quality (IAQ). Research on the relationship between IAQ and energy conservation and developing measurement and mitigation technologies.

Funding for this work totaled $45 million in FY 1991. The budget request for FY 1992 is $55 million. The planning level calls for continuing rapid increases, possibly reaching $135.2 million in FY 1994. DOE has then projected funding to remain relatively constant through FY 1997 (U.S. Department of Energy 1991b).

Inventory of OBT Environmental Projects

During FY 1990, OBT sponsored development of an inventory of recent OBT studies directly related to environmental issues to support its planning for activities responsive to environmental needs (Farhar and Kenaston 1990). This inventory includes detailed information on 14 projects directly related to the environment. These projects can be grouped in three categories: (1) CFC substitutes for refrigeration equipment, (2)

incorporating the cost of externalities into utility electricity generation, and (3) indoor air quality topics.

CFC Substitutes for Refrigeration Equipment. Three studies are included in this category. The first is the Report to the Secretary of Energy on Ozone-depleting Substances (Berg 1989). This study's aim was to determine the feasibility of reducing releases of ozone-depleting chemicals while increasing energy efficiency through use of CFC substitutes. The second is Environmentally Acceptable Refrigerants Research to develop environmentally safe substitute refrigerants and alternative refrigeration processes for replacing CFCs and to develop highly efficient, innovative refrigeration concepts into emerging technologies that can be readily adopted. The third was Nonazeotropic Refrigerant Mixtures Research. This work's aim is to design, test, and develop novel heat exchanger concepts using nonazeotropic refrigerant mixtures (NARMs) as potential CFC substitutes in household and commercial chiller applications.

Incorporating the Costs of Externalities into Utility Electricity Generation. Five studies fall into this category. The first is a Survey of State Public Utility Commission (PUC) Activities to Incorporate Environmental Externalities into Electric Utility Planning and Regulation. Awareness of the environmental consequences of electricity production has led some state PUCs to formally consider externalities in their regulation of utilities. Data were gathered on the extent of this concept's use in planning or rate-making, supply/demand balance, and resource planning and acquisition (Cohen et al. 1990a).

OBT funded the Center for Clean Air Policy to conduct two other studies, one on acid rain and the other on greenhouse gases. The Acid Rain and Greenhouse Gases Dialogues provided a forum for energy experts to identify and rank demand side options to reduce acid rain and greenhouse impacts through a 10 million ton SO_2 emissions

reduction by examining two utility service areas (Neme and Nixon 1989). The study analyzed the impacts of two alternative conservation scenarios on acid rain control costs, utility operating costs, and other variables. The study also compared the reduction costs with those associated with the use of conventional technologies, including scrubbers and tree planting options.

Another study, Analysis of the Impacts of Environmental Externalities Programs on Rates, assessed the impacts that environmental externalities accounting methods would have on electric utility rate-making in the Northeastern United States (Cohen et al., 1990b). A final study in this category, the Environmental Costs of Electricity, created an annotated bibliography of environmental externalities accounting approaches and an assessment of further research opportunities (Ottinger et al. 1990; Ottinger 1990).

Indoor Air Quality (IAQ) Topics. Six projects addressed IAQ; this was the most well-developed area of inquiry directly related to environmental problems.[3] IAQ research arose from concerns about radon and more tightly weatherized housing. IAQ research included projects on

- Indoor Organic Chemistry to determine the role of volatile organic chemicals (VOCs) in indoor air quality (e.g., Hodgson, Daisey, and Grot 1989).
- Ventilation and Indoor Air Quality Control to develop energy-efficient and cost-effective control technologies for radon, VOCs, and biologically active aerosols (e.g., Daisey and Hodgson 1989).
- Radon Characterization and Mitigation Study to develop measurement techniques for radon levels and the factors that affect them (e.g., Sextro et al.

[3]This paper does not emphasize IAQ because it focuses on atmospheric problems.

1988).

- Forced Convection Ventilation Flow Modeling Research to develop laboratory capabilities to study the relative effectiveness of various ventilation systems and strategies (e.g., Anderson 1989).
- Indoor Air Quality, Infiltration, and Ventilation Research to develop test methods on air movements in large commercial buildings (e.g., National Institute of Health 1990).
- Infiltration and Ventilation Measurement and Modeling to develop and test measurement techniques and models for determining energy requirements associated with air infiltration and ventilation rates (e.g., Sherman 1990).

The bulk of the OBT program indirectly affects the environment by reducing the use of energy in buildings from nonrenewable sources. The research program described develops energy efficiency and RETs for use in buildings. To realize environmental benefits from buildings energy efficiency and use of renewables, these technologies need to be transferred to building researchers, product manufacturers, energy intermediaries (architects, builders, building managers, code officials, lenders, real estate agents, and so on), energy service deliverers (utilities, energy service companies, fuel suppliers, and others), federal programs, information intermediaries, communities, and energy end users (consumers).

Planning Environmentally Sensitive Buildings Energy Research and Technology Transfer

As noted, the OBT's goal is no increased use from 1990 levels of nonrenewable energy in the U.S. buildings sector. This is highly desirable from an environmental point of view. If this could be accomplished, emissions would be reduced, thus improving global environmental quality. Ashton, McDonald, and Nicholls (1991) have identified three types of technical options for reducing greenhouse gas emissions from buildings energy use: (1)

restructuring energy service demand; (2) improving energy-efficient design, siting, and construction along with operations and maintenance; and (3) switching to low-carbon fuels for power generation.

Along these lines, some concepts that DOE is pursuing include the following:

1. Improving energy efficiency overall in end-use applications. For example, DOE is favorable to the "Golden Carrot" initiative, a new incentive program proposed by a coalition of utility, industry, state government, and public interest groups, with EPA support. The initiative's aim is to provide a financial incentive, targeted at product manufacturers and possibly at consumers, to accelerate the introduction of energy-efficient technologies. The first target is to develop and market, by the late 1990s, a non-CFC refrigerator/freezer at least 30% more efficient than the 1993 DOE standard. To do this, a $20-30 million pool of funds would be assembled from utility and other sources.

2. Developing alternatives to CFCs, and over a longer time scale, HCFCs. This work includes expanded research on alternative refrigeration cycles that do not require CFCs or HCFCs, research on lubricants and materials compatible with CFC substitutes, the development and testing of non-CFC blowing agents in insulation, and the development of advanced insulation concepts requiring no CFCs or HCFCs, such as vacuum insulation technologies.

3. Developing and promoting renewable energy technologies (RETs). RETs such as solar thermal, wind energy systems, and photovoltaics (PV) as well as hydropower are currently supplying 8% of the nation's energy needs (Idaho National Engineering Laboratory et al. 1990). These nonfossil fuel sources of electricity can increasingly displace fossil-fuel generated electricity. Also, desiccant cooling uses solar thermal energy as the regenerator. This technology also improves IAQ. PV can also be used in buildings in

which the building structure is used as the framework to support the PV arrays, therefore reducing costs and making PV more cost-competitive with alternatives. Related technologies are "smart windows" and "smart envelopes" where the electricity from PV is used to change the light transmittance or thermal transfer of the glazing or the opaque building envelope.

4. Changing the energy service demand. An array of possibilities exist for providing comfort and other energy services through means other than the utility grid and fossil fuels. For example, design concepts to use daylighting in residential and commercial buildings result in reduced electricity loads. Water for homes can be heated through solar energy systems using solar collectors. Trees can be planted around buildings to provide natural cooling and reduce the amount of CO_2 in the atmosphere. Passive solar building principles, such as proper orientation, can contribute significantly to a building's energy services.

5. Developing a community systems approach to energy demand. This is important because the net effect of several buildings is different than the effect of each individual building. For example, cogeneration and district heating and cooling systems can use the "waste heat" of power generating systems. A district cooling system might also use ammonia (a non-CFC) as a refrigerant because of the ability to separate the cooling plant from populated areas of buildings and to control its safety problems more effectively.

The National Energy Strategy identified seven options for maintaining or enhancing comfort, indoor air quality, and affordability of residential and commercial buildings, while reducing energy use (U.S. Department of Energy 1991a). These included the following.

1. Expand R&D on a wide range of more energy-efficient building technologies.
2. Continue support of state and utility programs. This includes the

weatherization of homes occupied by low-income households, the retrofit of institutional buildings, incentives for the purchase of energy-efficient appliances, and consumer information programs.

3. Expand use of mortgage financing incentives for residential energy efficiency. This will develop and encourage the voluntary acceptance of efficiency ratings and their use in home financing.

4. Improve the efficiency of public housing. Innovative incentives will be provided for managers and tenants to use energy more efficiently.

5. Set cost-effective appliance and equipment standards and provide information to consumers through a labeling program. DOE has provided labeling for 13 categories of appliances and for fluorescent lighting system ballasts.

6. Develop and encourage the use of building efficiency standards. State and local governments will receive technical assistance to promulgate and implement these standards.

7. Improve federal energy efficiency. Federal agencies will continue and strengthen their efforts to improve the efficiency and management of their facilities.

The newly released NES is based on a three-part foundation--increasing energy and economic efficiency, securing future energy supplies, and enhancing environmental quality. The NES makes explicit that protecting the environment is integral to national energy policy. Implementation of the NES is still to come: steps to begin are being taken now. The prospects for improving environmental quality through increasing U.S. buildings energy efficiency and the use of renewable energy technologies are encouraging.

Acknowledgements

The Solar Energy Research Institute is operated for the U.S. Department of Energy by Midwest Research Institute under Contract No. DE-AC02-83CH10093. Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract No. DE-AC06-76RLO 1830. The Office of Building Technologies provided funding for the work on which this paper is based. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

References

Anderson, R. 1989. *Impact of Ventilation Design on Exposure to Indoor Air Pollutants*, Golden, CO: Solar Energy Research Institute.

Ashton, W.B., S. C. McDonald, and A. K. Nicholls. 1991. "Global Options for Reducing Greenhouse Gas Emissions from Residential and Commercial Buildings," Revised Working Paper for the Dahlem Conference on Limiting the Greenhouse Effect, Berlin, Germany, December 9-14, 1990. Washington, D.C.: Pacific Northwest Laboratory.

Berg, John R. 1989. *Report to the Secretary of Energy on Ozone-Depleting Substances: An Analysis of the Energy and Economic Effects of Phasing Out Certain Organic Chlorine and Bromine Products.* Washington, D.C.: U.S. Department of Energy, Office of Building Technologies.

Cohen, S.D., J. H. Eto, C.A. Goldman, J. Beldock, and G. Crandall. 1990a. *A Survey of State PUC Activities to Incorporate Environmental Externalities into Electric Utility Planning and Regulation.* Washington, D.C.: National Association of Regulatory Utility Commissioners.

Cohen, S.D., J. H. Eto, C.A. Goldman, J. Beldock, and G. Crandall. 1990b. "What States Are Doing about Externalities." *The Electricity Journal,* 24-25.

Daisey, J. M. and A. T. Hodgson. 1989. "Initial Efficiencies of Air Cleaners for the Removal of Nitrogen Dioxide and Volatile Organic Compounds," *Atmospheric Environment, 23*: 1885-1892.

Edmonds, J.A., W. B. Ashton, H.C. Cheng, M. Steinberg. 1989. *A Preliminary Analysis of U.S. CO_2 Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010.* Washington, D.C.: Pacific Northwest Laboratory and Brookhaven National Laboratory.

Farhar, B.C., and J. Kenaston. 1990. *Status Report, Environmental Projects Data Base.* Washington, D.C.: Solar Energy Research Institute.

Hodgson, A.T., J. M. Daisey, and R.A. Grot. 1989. "Source Strengths and Sources of Volatile Organic Compounds in New Office Buildings," in *Proceedings of the 82nd Annual Meeting of the Air and Waste Management Association,* Paper No. 89-80.7, Berkeley: Lawrence Berkeley Laboratory.

Idaho National Engineering Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratories, Solar Energy Research Institute. 1990. *The Potential of Renewable Energy, An Interlaboratory White Paper*, SERI/TP-260-3674. Golden, CO: Solar Energy Research Institute.

Intergovernmental Panel on Climate Change 1991. *Climate Change: The IPCC Response Strategies*. World Meteorological Organization/ United Nations Environment Program. Washington, D.C.: Island Press.

McNutt, B. 1990. Letter to Members of the Sub-Group on Energy Conservation, 25 January, 1990.

Miller, R.B. 1990. "Global Change Research Activities in the Social and Economic Sciences." White paper, Division of Social and Economic Science, Washington, D.C.: National Science Foundation.

National Institute of Health. 1990. *Mathematical Models Describing Ventilation within a Room*. Gaithersburg, MD.

Neme, C. and E. Nixon. 1989. *An Efficient Approach to Reducing Acid Rain: The Environmental Benefits of Energy Conservation.* Washington, D.C.: Center for Clear Air Policy.

Office of Science and Technology Policy. 1991. *Our Changing Planet: The FY 1992 U.S. Global Change Research Program.* A Report by the Committee on Earth and Environmental Sciences, Reston, VA: U.S. Geological Survey.

Ottinger, R. L. 1990. "Considerations of Environmental Externality Costs in Electric Utility Resource Selections and Regulations," in the *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, Washington, D.C.: American Council for an Energy Efficient Economy.

Ottinger, R. L., D. R. Wooley, N. A. Robinson, D. R. Hodas, S. E. Babb, S. C. Buchanan, P. A. Cernick, E. Caverhill, A. Krupnick, W. Harrington, S. Radin, U. Fritsche. 1990. *The Environmental Costs of Electricity.* Dobbs Ferry: Oceana Publishing Co.

Price, M. F. 1990. *The Human Aspects of Global Change*, Boulder, CO: The National Center for Atmospheric Research.

Sextro, R.G., B. H. Turk, J. Harrison, K. L. Evzan, and A.V. Nero. 1988. *Radon Entry and Control in Seven Homes with Basements.* Berkeley, CA: Lawrence Berkeley Laboratory.

Sherman, W. 1990. "A Pow[illegible]aw Formulation of Laminar Flow in Short Pipes," Berkeley, CA: Lawrence Be[illegible]ey Laboratory.

Statt, T.G. 1988. "Use of Chlorofluorocarbons in Refrigeration, Insulation, and Mobile Air Conditioning in the USA," *International Journal of Refrigeration, 11.*

U.S. Department of Energy. 1989a. *Potential Costs of Restricting Chlorofluorocarbon Use.* Washington, D.C.: Energy Information Administration.

U.S. Department of Energy. 1989b. *State Energy Data Report: Consumption Estimates, 1960-1988*. Washington, D.C.: Energy Information Administration.

U.S. Department of Energy. 1991a. *National Energy Strategy. Executive Summary, First Edition*. 1991/1992. Washington, D.C.

U.S. Department of Energy. 1991b. *Office of Conservation and Renewable Energy Multi-year Program Plan* (Draft), Fiscal Years 1993-1997, Washington, D.C.

U.S. Government Printing Office. 1991. *National Energy Strategy*. First Edition. Washington, D.C.

END

DATE FILMED

10 / 29 / 91