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UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

ENERGY EFFICIENT BUILDINGS PROGRAM

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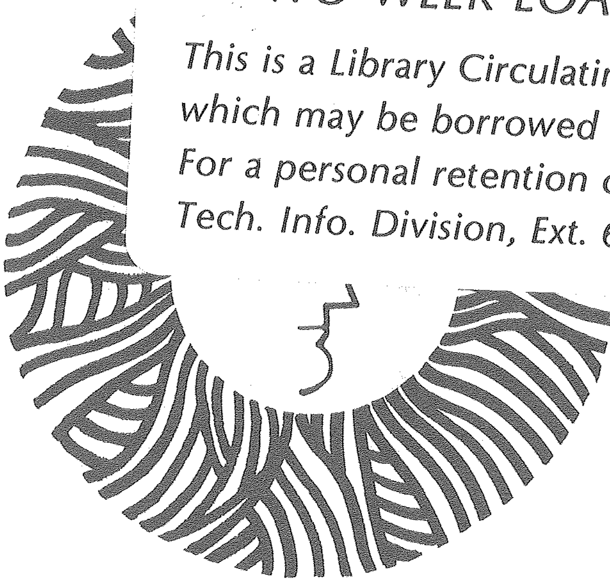

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DISCLAIMER

ENERGY EFFICIENT BUILDINGS PROGRAM

FY-1979

The research reported in this volume was undertaken during FY 1979 within the Energy & Environment Division of the Lawrence Berkeley Laboratory. This volume will comprise a section of the Energy & Environment Division 1979 Annual Report, to be published in the summer of 1980.

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FEBRUARY 1980

ENERGY EFFICIENT BUILDINGS PROGRAM

INTRODUCTION

A. H. Rosenfeld, C. D. Hollowell, S. Berman, and T. Edlin

The Energy Efficient Buildings (EEB) program conducts both theoretical and experimental research on various aspects of building technology. An important goal of the program is to identify, assess and recommend solutions to problems that interfere with national goals of conserving energy consumed by the buildings sector. Buildings account for approximately 38% of the total energy consumed in the United States, in contrast to automobiles, which consume approximately 18%.

One focus of our investigations during the past several years has been on Building Performance. Building performance is assessed by regarding the building as a system; in this framework, performance is tested in terms of air infiltration rates, thermal characteristics of building components and the behavior of the joinder interface between dissimilar materials. The program devises cost-effective solutions to reduce infiltration and thermal losses, both by retrofitting existing buildings and gathering data on which revised standards for new buildings can be promulgated. This research on air infiltration and thermal performance of the building and its components is conducted in the field, in the laboratory, in our research house and on computer models.

Another major area for the EEB program is Ventilation and Indoor Air Quality (VIAQ). The VIAQ group is identifying, characterizing and monitoring indoor levels of various pollutants in conventional and energy-efficient buildings with specific attention to their impact on indoor air quality. Reducing air infiltration, the most obvious means of improving a building's energy efficiency, can "seal in" indoor air contaminants and have mild to severe repercussions on the health and comfort of building occupants. This group is concomitantly investigating means of preventing and controlling indoor air pollution without compromising energy conservation goals. In this connection, it has tested various ventilation systems with air-to-air heat exchangers at a number of locations throughout the country.

The Windows and Lighting section of the EEB program is emphasizing ways to encourage industry to develop and promote energy-efficient products at cost-effective prices. A primary consideration in the Windows group is to assure that daylight is provided to the building's interior with minimum thermal loss in cool weather and minimum thermal gain in hot weather. To this end, considerable research activity has centered on developing and testing optical coatings for windows as well as evaluating a number of window treatments now available commercially or to be made available in the near future.

The Lighting program is concentrating on developing energy-efficient lighting systems (lamps, ballasts, fixtures and controls) to provide lighting designers with an array of design options to meet occupant needs. One recent development currently being field-tested in several buildings is high-frequency, energy-efficient solid-state ballast for fluorescent lights that effects a 25% savings over conventional core ballasts.

The Building Energy Analysis Group is responsible for developing, improving and documenting the computer program, DOE-2, which has been designated as the national program for calculating building energy performance standards. DOE-2 can also be used by architects/engineers as a means of quickly and effectively optimizing building design to improve its energy efficiency and minimize life-cycle costs. DOE-2 will be systematically updated to incorporate the latest energy-conserving design features (passive and active solar, thermal storage, natural ventilation, daylighting, and evaporative cooling).

DOE has commissioned LBL to develop parametric profiles to quantify the energy requirements of residential buildings, including heating and cooling systems. This work, being accomplished by the BEPS/AEPS Group uses the DOE-2 modeling program to evaluate a wide variety of conservation measures for different house designs and climates in terms of life-cycle costs of implementation.

The reader who is interested in the national energy savings that might be effected as a result of our research is referred to the Summary Section of this chapter which presents data on the potential impact of a national retrofit program and the adoption of energy-efficient building performance standards.

The work described in this entire chapter was funded by the Office of Buildings and Community Systems, Assistant Secretary for Conservation and Solar Energy of the U.S. Department of Energy under contract number W-7405-ENG-48.

BUILDING ENVELOPES PROGRAM

R. C. Sonderegger, R. T. Beerman, A. K. Blomsterberg, W. L. Carroll, J. A. Casey, P. E. Condon, R. C. Diamond, D. T. Grimsrud, D. L. Krinkel, C. W. Ma, M. P. Modera, A. H. Rosenfeld, M. H. Sherman, and B. V. Smith

INTRODUCTION

Residential and commercial buildings account for one-third of the total energy use in the United States today. Approximately 60% of the energy consumption in these sectors is for space heating and air conditioning.[1] Conductive losses through the windows, walls, and roof of the structure account for 2/3 to 3/4 of the 60%, while air infiltration through cracks in the walls, around doors, windows, fireplaces, or any other opening in the building envelope accounts for 1/4 to 1/3 of the 60%.

The Building Envelopes Program was initiated in April 1977 as part of Lawrence Berkeley Laboratory's broad-based study of energy conservation in buildings. The main objective of the program is to provide fundamental information on the thermal performance of a building so that appropriate energy-conserving guidelines and standards governing the design and construction of new buildings as well as retrofit strategies for existing buildings can be recommended or prescribed. A comprehensive research undertaking in this area requires not only systematic study of individual components within the building envelope, but also a careful examination of the energy performance of the building as a whole.

Work carried out during FY 1978 centered around four principal experiments undertaken at LBL's research house in Walnut Creek:

- Tracer gas techniques to measure air infiltration.
- Pressurization tests for air leakage.
- Investigations of heat loss through walls.
- Electric co-heating runs to measure fireplace efficiencies.

The research house is a typical wood-frame, three-bedroom, suburban ranch house built in 1964 (see Fig. 1). After developing the experimental procedures at the research house, we surveyed several houses in the Bay Area to determine the applicability of these procedures to other houses.

ACCOMPLISHMENTS DURING 1979

Four projects are currently underway: the first three are continuations of past work on air infiltration, thermal performance of walls, and fireplace testing; the fourth is a new effort to provide an audit procedure for energy conservation in residences.

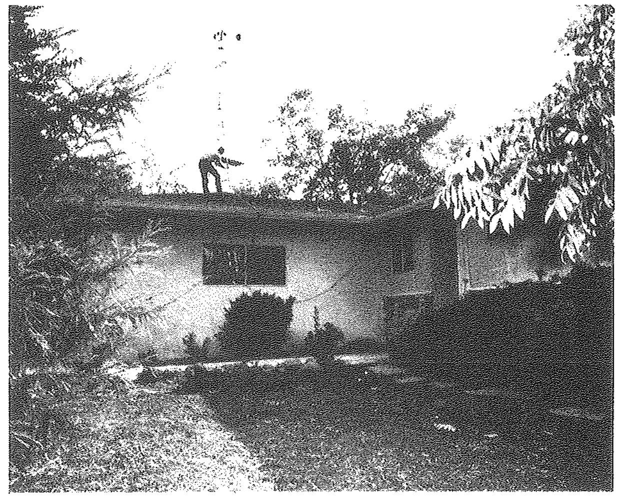

Fig. 1. Research House in Walnut Creek, California. (CBB 7811-14961)

Air Infiltration Studies

Air infiltration rates are one of the large unknowns in any analysis of building energy use because they involve variable pressures caused by both wind and indoor/outdoor temperature differences, as well as construction features and occupant behavior. Our studies in this area are largely concerned with measuring, modeling, and reducing air infiltration. Considerable attention has been given to correlating air-leakage measurements obtained through fan pressurization of a house with the infiltration rates occurring naturally. An important goal of our research program is to facilitate the development of standards regulating air leakage in residential construction. Several critical issues dealing with air infiltration are discussed in LBL reports concerning Building Energy Performance Standards (BEPS) and Construction Quality Standards.[2,3]

Two general strategies are possible to save dollars and energy lost through air infiltration. The first is to tighten the envelope of existing buildings (by caulking, weatherstripping, etc.) until the infiltration rate is brought down to approximately 0.5 air changes per hour (ach) under typical weather conditions. The second strategy requires careful attention during the construction of new buildings to ensure the integrity of the thermal envelope. In houses where infiltration rates are significantly reduced in order to make them more energy efficient, indoor air quality can deteriorate unless adequate ventilation is provided. Mechanical ventilation systems with heat exchangers provide sufficient fresh air without excessive heat loss. Research on various aspects of indoor air quality and on residential heat-recovery devices constitute a major part of the Energy Efficient Buildings program and is described elsewhere in this report.

ACCOMPLISHMENTS DURING 1979

Air leakage, surface pressures and air infiltration were measured in several conventional and energy- efficient houses located throughout the United States.[4-6] Among the houses tested were the Minimum Energy Dwelling (MED I) in Southern California, three energy-efficient houses in the Midwest (two privately built, one a test house at Iowa State University) a group of active-solar houses in Davis, California, and a number of conventional houses in the San Francisco Bay Area. Air-leakage values for these houses are shown in Fig. 2.

Air infiltration measurements taken during the survey were compared with infiltration rates predicted by a simple model combining air- leakage values taken from fan pressurization and measured surface pressures. The comparison between measured and predicted values is shown in Fig. 3.

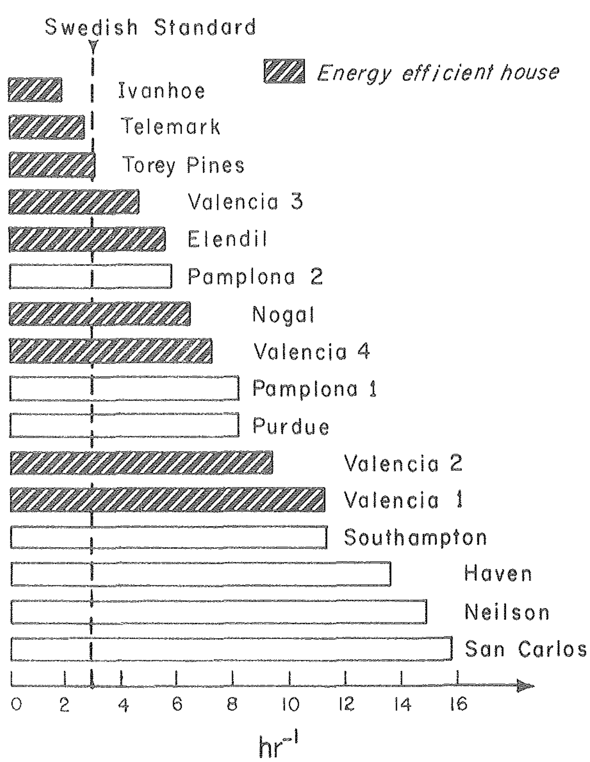

Fig. 2. Air leakage rates, in air changes per hour at a pressure of 50 pascals, for U.S. homes measured in LBL survey. Swedish building standard indicated by dashed line. (XBL-796-1754A)

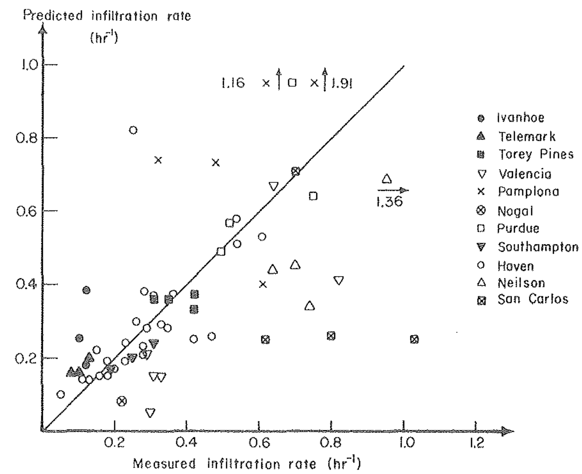

Fig. 3. Predicted vs. measured infiltration rates for survey houses. (XBL-796-1856A)

Two new models were developed to correlate air leakage and infiltration.[7,8] In addition, a technique that examines the low- pressure leakage function of a residence by means of an oscillating pressure source was developed and tested. The advantage of this method is that it simulates the low-pressure range where natural infiltration occurs, and is independent of weather interactions.[9] Such information is essential in constructing a predictive model of infiltration.

The Envelopes group was also responsible for developing instrumentation for other EEB groups conducting related research. An automated tracer-gas system was designed and built for the EEB mobile trailer and for the Passive Solar Group for their measurements of air infiltration.

A final effort this year has been to establish a U.S. Data Center for infiltration research coordinated with the International Energy Agency Center at BSRIA, England. The data center will hold bibliographical and numerical data for North American research in air infiltration and related studies. The computer software for the data base was completed, and data entries have begun.

PLANNED ACTIVITIES FOR 1980

Work will continue on the infiltration-pressurization correlations, instrumentation development, and the updating and maintaining of the infiltration data center. New work will focus on designing simplified models of infiltration to be used in the LBL Residential Energy Audit and detailed infiltration models to be used in the DOE-2 infiltration algorithm.

To verify these models, a new laboratory is being designed, the Mobile Infiltration Test Unit (MITU), which will allow us to conduct long-term measurements of surface-pressure distribution under different weather conditions and terrains, and with different structural leakage characteristics. Results from these tests will yield improved confidence limits on infiltration- pressurization correlations.

An important activity begun in FY 1979 and to continue in FY 1980 is the cooperative work with builders, utilities, and other researchers in the building industries. The following projects are already underway: a Johns-Manville/EPRI air-leakage study in Denver, a collaboration with Rochester Gas and Electric and New York State Energy Research and Development Authority on air leakage in new homes, work with Bonneville Power Administration on retrofitting a group of existing houses in Washington state, and work with Pacific Gas and Electric Company in a cooperative program with builders and contractors to reduce air leakage in existing homes.

Thermal Performance of Walls

The actual thermal performance characteristics of building walls are largely unknown. Available information is based on theoretical analysis and laboratory tests. Even though a wall may be well designed, differences in construction methods and aging of materials can produce substantial variations in thermal performance. Where actual measurements have been made in buildings, the thermal resistance of the walls is often 20% to 30% less than that predicted by laboratory measurements and standard calculations. Ultimately, recommendations for energy conservation standards should be based on accurate measurements of building walls, rather than on largely unverified inferences from laboratory measurements and computer models. The purpose of this research is to develop techniques for field (or in-situ) measurement of the thermal performance of walls. The improvements being developed fall into two broad categories: better equipment for collecting raw data, and better methods of data reduction using computers.

ACCOMPLISHMENTS DURING 1979

In order to measure the thermal resistance and the dynamic thermal response of building walls, a new device, the Envelope Thermal Test Unit (ETTU) was designed and built this year. The prototype ETTU is based on an analysis of complex thermal admittance, and uses a microprocessor for sophisticated on-line computer control and data analysis.[10]

A second, simpler ETTU (ETTU-II) was invented this year. Error analysis for ETTU has shown that the form of the controlled drive signal is not a critical design parameter. Instead of controlling the heat flows through the wall boundaries, as is done in ETTU, the new design uses newly developed heat flow sensors to measure the naturally occurring heat flows. These sensors will measure heat flows and average temperatures across large wall areas (20 to 30 ft^2).

Fig. 4. Envelope Thermal Test Unit (sandwiched between vertical plywood panels) during calibration check at laboratory. (XBB 790-16280)

PLANNED ACTIVITIES FOR 1980

We have several goals for the coming year. One project will focus on the use of ETTU as a portable field-testing apparatus to investigate any change in thermal performance with age in a representative sample of actual house walls. Another project is to develop the large heat-flux sensor for the passive system, ETTU-II. The sensor will have a sensitive region of about 1 x $1.5 m^2$ (3′ x 5′) and thermal resistance of less than about $.002^{\circ}C\ m^2/W$ ($.01^{\circ}F\ ft^2\ hr/Btu$). The technique uses thin film resistors on two sides of a plastic sheet. The temperature difference across the sheet is measured by using the temperature dependence of the electric resistance. Both ETTU systems will be validated by using standard reference materials calibrated in conventional laboratory test facilities. Other projects include the continued collaboration with the ASTM C16 committee on thermal and cryogenic insulating materials in defining appropriate parameters for characterizing thermal wall performance, and the dissemination of the data collection/reduction system developed for ETTU.

Fireplace Testing

With the recent surge of interest in heating houses with wood, and the appearance on the market of hundreds of accessories for improving the efficiency of fireplaces, LBL initiated the development and subsequent testing of a standardized procedure for measuring fireplace efficiency.

In this procedure, called electric co-heating, several electric heaters are distributed throughout the house. Temperature sensors located in each room ensure that a constant temperature is maintained by the heaters. When the fire is burning, there is a reduction in the heat output of the electric heaters; by measuring the amount of this reduction, we can determine the net efficiency of the fireplace.[11] The advantage of using electric co-heating to measure fireplace efficiency is that it is an in-situ measurement that takes into account the combined effect of the radiant heat gain from the fire and the heat loss from additional air infiltration caused by the chimney draft.

ACCOMPLISHMENTS DURING 1979

Using the co-heating technique, we measured the efficiency of the fireplace, furnace, and air-conditioning unit in the Walnut Creek research house, where we also tested seven fireplace accessories, ranging from simple convective grates to combination units with blowers and glass doors. The tests were later repeated at a mountain test site where the climate was more severe.

The results from a 9-hour test are shown in Fig. 5. The run is divided into three periods: before, during, and after fireplace operation. The top line is the total electric consumption needed to maintain a constant temperature throughout the house. The lower lines designate the electricity consumption for the heaters in the living room/kitchen (where the fireplace is located) and for the bedrooms. Air infiltration increases significantly while the fire is burning. This increase in air infiltration cools the bedrooms, which are not receiving the radiant energy from the fire. The graph shows this effect as an increase in electrical consumption by the bedroom heaters.

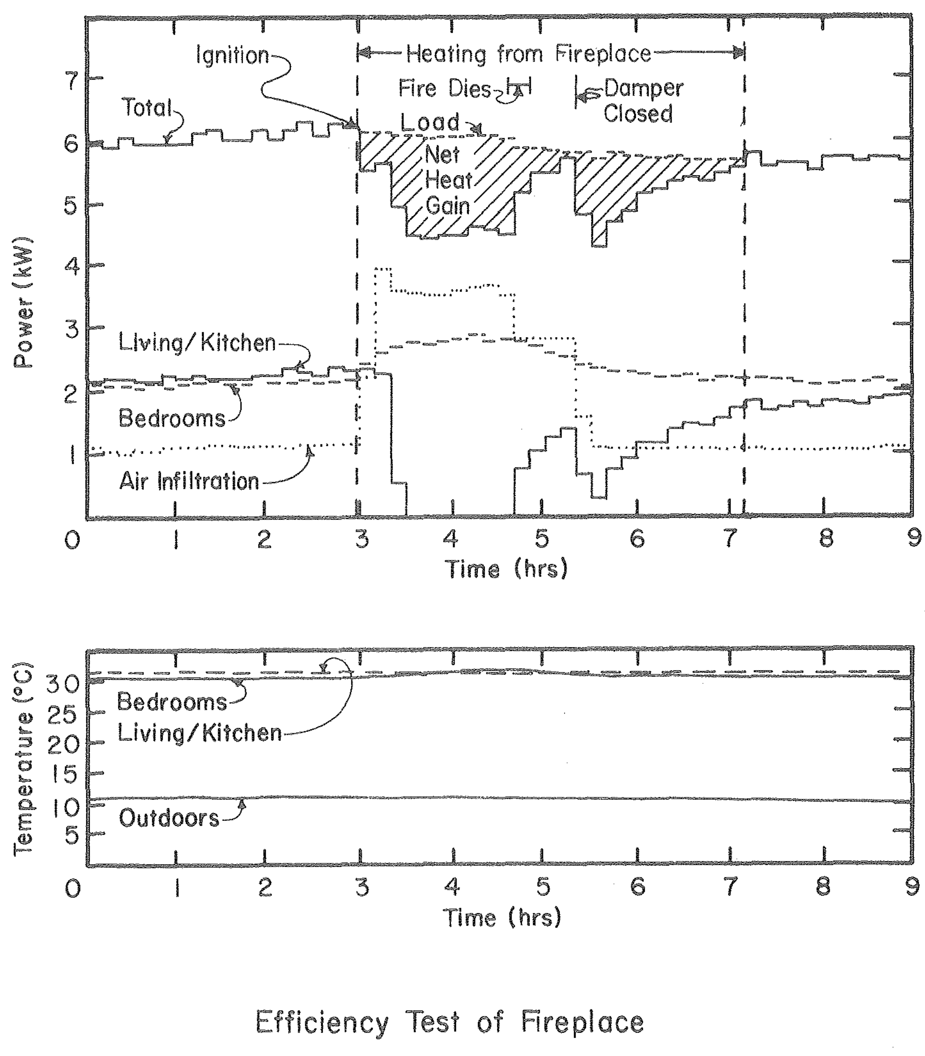

Fig. 5. Efficiency test of fireplace. (XBL 7910-12350)

Results of our tests showed that a common masonry fireplace is only about 5% efficient, and that this efficiency decreases in colder weather. The best of the fireplace accessories was 30% efficient, still far below the 70% efficiencies achieved by airtight woodburning stoves.[12] With the cost of wood at $100 per cord, useful heat from a fireplace at 20% efficiency costs $21 per million Btu. By comparison, heating with fuel oil at 60% efficiency costs $9 per million Btu, and heating with natural gas at 70% efficiency costs $5 per million Btu.

PLANNED ACTIVITIES FOR 1980

No new testing is planned. Follow-up activities will be the publication of a technical report on our experiments and a consumer brochure on fireplaces and fireplace accessories.

Residential Conservation Service Audit

The Residential Conservation Service (RCS) was established by the 1978 National Energy Conservation Policy Act, which requires that major public utility companies and fuel- oil dealers provide a house energy audit to customers who request it. States have two options in complying: either they submit a plan for DOE approval, or DOE will mandate its own energy audit (currently being developed by ORNL and SERI). In accordance with RCS regulation, this audit will be site- and house-specific, will consider both conservation and renewable resources (solar and wind) in its recommendations, and will give the homeowner a cost-benefit analysis of the recommended measures.

Because of time/cost restrictions inherent in the basic audit, DOE commissioned LBL to develop an expanded residential energy audit. The novel features of this audit are the inclusion of a portable microcomputer for evaluating appropriate retrofits based on input collected during the audit, and the undertaking of several simple retrofits at the time of the visit. (Our current experience in retrofitting at the time of the audit shows a 15-20% reduction in air leakage by caulking and sealing cracks).

The expanded audit will require an initial screening of utility bills and weather data to obtain an "energy signature" for the house. The auditor and assistant then make a three hour visit to the house where they record window types and dimensions, test the envelope for leakage with a blower door that pressurizes or depressurizes the house, identify leaks, plugging the easy ones as they go and noting the more difficult ones to repair later. While the auditor measures furnace efficiency, checks water and air-temperature settings, and estimates envelope R-values, the assistant continues to fix leaks, installs water-heater insulation, changes the air filter in the furnace, calibrates the thermostat and, with the permission of the homeowner, installs a low-flow showerhead and resets the water-heater thermostat.

At the conclusion of the physical inspection, all necessary data are collected and fed to the microcomputer. The auditor then confers with the homeowner on a suitable retrofit package. The computer will scan a master list of possible retrofits stored on a disc that contains conservation measures such as insulation, storm and double-pane windows, insulating shutters, caulking and weatherstripping, and active- and passive- solar retrofits for space and water heating.

The computer will give retrofit packages for several budgets, along with costs and savings of the entire package. Retrofits can be tailored to the preferences of the homeowner with a very short turnaround time. All cost estimates take into account the possibility that the homeowners may provide the labor for doing the retrofits themselves. At the conclusion of the visit, the auditor leaves detailed information on the suggested retrofits with the homeowner.

ACOMPLISHMENTS DURING 1979

LBL began work on the energy audit at the end of FY 1979, and will make it a major effort in FY 1980. Several features have already been incorporated that distinguish it from the basic audit and other residential energy audits used by utilities and private businesses:

- The cost-benefit calculations rely heavily on actual data of the thermal characteristics of the house as measured on-site at the time of the audit, and on past fuel consumption data obtained from utility or fuel-dealer records. Past fuel bills will be analyzed to determine marginal heating consumption per additional degree-day, and "free" heat provided by appliances. Both quantities are important for estimating the cost-effectiveness of retrofits and, later, for evaluating the success of the conservation measures adopted.

- The audit is user-oriented, i.e., it allows homeowner preferences for particular retrofits and homeowner plans for house additions to be integrated in the calculations.

- The audit uses state-of-the-art analytical techniques including a simplified calculation of thermal storage effects for estimating energy savings due to heat-loss reduction, solar-gain enhancement and heating efficiency improvements as well as energy savings due to sensible, latent and radiative heat-gain reductions and cooling-system efficiency improvements. (Most audits rely on simplified steady-state load calculations, often without adequate treatment of solar-heat gain and air infiltration).

- The audit will calculate life-cycle costs and savings resulting from installation, operation and replacement of installed retrofits.

PLANNED ACTIVITIES FOR 1980

Work for FY 1980 will involve the completion of the audit procedure and the validation of this approach with actual measurements on several houses.

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BUILDING VENTILATION AND INDOOR AIR QUALITY PROGRAM

INTRODUCTION

C. D. Hollowell

The Building Ventilation and Indoor Air Quality (VIAQ) Program is a major component of Lawrence Berkeley Laboratory's (LBL) Energy Efficient Buildings Program (EEB). Funded by the Department of Energy (DOE), Office of Buildings and Community Systems (BCS) and the Office of Health and Environmental Research (OHER), the VIAQ Program is part of a coordinated effort to respond to the need for conserving the nation's energy while maintaining the health and comfort of occupants of the built environment. The overall objective of the Ventilation Program is to conduct in-depth research and development on existing and proposed ventilation requirements and mechanical ventilation systems in order to provide recommendations for the establishment of energy-efficient ventilation standards and ventilation designs for residential, institutional, and commercial buildings. LBL is also providing both technical and management support to DOE headquarters for other related ventilation projects.

VIAQ Program activities for FY 1979 represent a continuation of the following tasks:

1) field monitoring of indoor air quality;

2) laboratory studies of building materials emissions, and health risk assessment studies;

3) demonstration and assessment of mechanical ventilation systems utilizing air-to-air heat exchangers;

4) continuation of subcontract activities consisting of:

   - assessment of ventilation requirements for odor control in buildings;

   - assessment of hospital ventilation standards;

   - study of automatic variable ventilation control systems based on air quality detection in institutional and commercial buildings.

5) completion and implementation of a ventilation-indoor air quality data base.

Residential, institutional, and commercial buildings account for approximately one-third of the energy consumed annually in the United States, (see Fig. 1). More than half of this energy is used to maintain human comfort conditions through the heating, cooling, and ventilating of buildings. Significant savings in the energy used to heat and cool buildings can be realized in at least two ways: 1) by changing the thermal properties of the structure; and 2) by reducing the natural and mechanical ventilation rates. The VIAQ Program is concerned primarily with the latter method.

Air changes in buildings take place through the random introduction of outdoor air by infiltration or its regulated introduction by natural ventilation or mechanical ventilation. In the United States, the latter mechanism is essentially limited to non-residential buildings. Ventilation, in general, is required in order to:

- Establish a satisfactory balance between the metabolic gases (oxygen and carbon dioxide) in the occupied environment.

- Dilute human and nonhuman odors to levels below olfactory threshold.

- Remove contaminants produced in the ventilated space by heating, cooking, construction materials, etc.

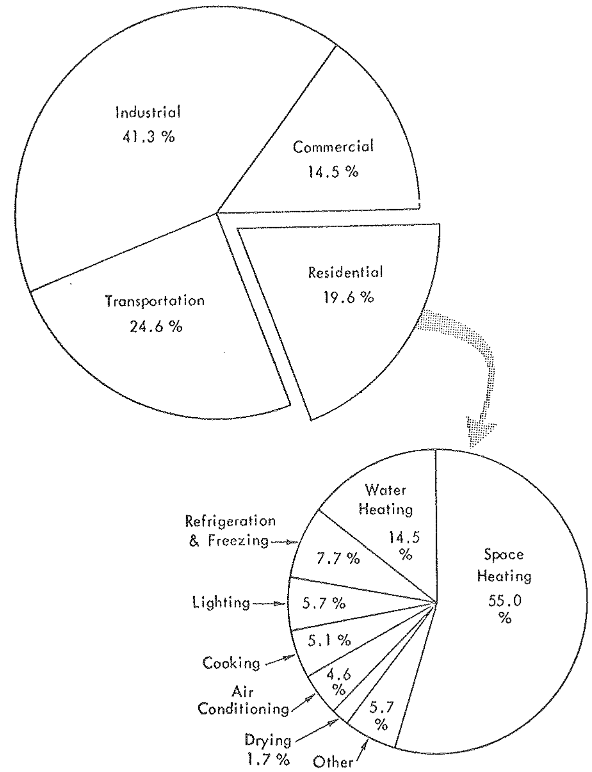

Fig. 1. Primary energy use, U.S., 1970:
(a) All sectors (~67 x 10^{15} Btu),
(b) Residential sector (~13 x 10^{15} Btu).
[Source: S.H. Dole, Rand Corporation, Energy Use and Conservation in the Residential Sector: A Regional Analysis, Santa Monica, Calif., June 1975, p. VI.]
(XBL 7911-12660)

- Remove excess heat and moisture from internal sources.

Ventilation requirements, currently set by state and local governments, vary from one jurisdiction to another. Most of the existing building codes, which contain references to ventilation requirements, are based on rather vague health and safety considerations and, in general, ignore energy conservation.

Through Public Law 94-385, Congress has mandated that Building Energy Performance Standards (BEPS) for new construction be promulgated by 1980 for adoption by state and local government jurisdictions having authority to regulate building construction through building codes and other mechanisms. The Department of Energy (DOE) is developing these standard and it is expected that results of VIAQ Program studies on ventilation requirements will be incorporated in future building energy performance standards.

Because heating or cooling outside air as it is introduced into a building requires a significant amount of energy, energy savings can be achieved simply by minimizing the use of fresh ventilation air. Table 1 illustrates the magnitude of the savings. If ventilation require-

Table 1. Potential energy savings† with energy efficient ventilation systems and lowered infiltration.

Total U.S. energy consumption	75 x 10^{15} BTU/yr
Total U.S. energy consumption for buildings	29 x 10^{15} BTU/yr
50% of building energy used to condition air (includes mechanical ventilation systems)	14.5 x 10^{15} BTU/yr
Assume ventilation requirements can be relaxed and infiltration lowered to give a 15% savings in energy used to condition air	
Potential energy savings	2.2 x 10^{15} BTU/yr
2.5% of national energy budget (7.5% of building energy budget)	1.0 x 10^{6} barrels of oil/day
At present prices of $30/barrel	Savings of $30 million/day

†1976 energy use estimates from Energy Research and Development Administration, Office of Conservation, "Buildings and Community Systems, Five Year Program Plan."[1]

ments were relaxed and infiltration reduced to save 12.5% of the energy currently used to condition indoor air, oil consumption could be reduced by one million barrels per day (2 quads* per year). The potential national impact, an annual savings of nearly $5 billion, is significant. In 1976, the United States imported 7.3 million barrels of oil per day at a cost of approximately $30 billion.[1] Specifically, this energy savings could be achieved by reducing infiltration by a factor of about two, in approximately two-thirds of existing residential buildings, and decreasing outside air requirements by a factor of two in approximately two-thirds of non-residential buildings.

The introduction of energy-saving measures in buildings, however, may adversely affect indoor air quality. The U.S., unlike some European countries, has not developed mandatory air quality standards specifically for the indoor environment. Nevertheless, we know that low air change rates may contribute to:

- the growth of mold on walls due to high internal humidity:
- the feeling of stuffiness arising from "stale" or polluted air; and
- the buildup of chemical contaminants emitted from building materials and other indoor sources.

It is anticipated that all of the projects in this program will produce data on energy conservation and indoor air quality that will be of important practical use not only to scientists and engineers, but also to building contractors, architects and related building trades people, as well as to the public at large. One of the principal means that will be used to disseminate this information is the LBL ventilation-indoor air quality data base. The main objective of the data base project is to collect research data and other pertinent information on building ventilation and to convert it into a form which allows users easy access through a computerized data management system.

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*One quad equals 10^{15} Btu.

GAS STOVE EMISSIONS

G. W. Traynor

INTRODUCTION

Field and laboratory measurements carried out thus far have indicated clearly that combustion-generated indoor air pollution may have a significant impact on human health. We have demonstrated that levels of gaseous air pollutants (CO, NO, NO_2 and aldehydes) and respirable particulate carbon and sulfur compounds are elevated in indoor environments where gas appliances are used--in the case of CO, NO_2 and aldehydes, approaching or exceeding promulgated and proposed ambient air-quality standards and in the case of respirable and particulate mass, comparable to those present on a very smoggy day.[1,2,3] Such high levels are unacceptable in terms of human health, safety and comfort, and must be taken into account particularly in energy-efficient structures where the reduction of infiltration may have serious ramifications on indoor air quality. Tables 1 and 2 summarize some of our findings with regard to gas stove oven and gas stove burner emissions, respectively, and present comparative values reported by others.

The work reported here represents the most recent accomplishments of our ongoing laboratory and field studies systematically examining gaseous and particulate air pollutants in residential buildings. The measurement techniques used in the field and laboratory experiments have been previously described.[2,3]

ACCOMPLISHMENTS DURING 1979

In our earlier laboratory studies, we quantified emission rates for a wide range of pollutants emitted by gas stoves, now identified as a significant source of pollution in the indoor environment. Tests were made with an environmental chamber about the size of a kitchen. Because the results obtained are not directly applicable to residences without enclosed kitchens, we initiated a project to equip an unoccupied experimental house with a gas stove and air-monitoring instrumentation to study 1) typical simulated exposures to pollutants generated by gas stoves, 2) the pollutant dispersion throughout the house, and 3) the role of infiltration and mechanical ventilation on indoor pollution levels.

A schematic of the Energy Efficient Buildings (EEB) research house used for these studies is given in Fig. 1. Only minor modifications were made to the house in order to reduce natural infiltration rates, e.g., sealing the unused ducts and fireplace. The house contains two mechanical ventilation systems. One is simply a fan-operated range hood installed directly over the gas stove (spot ventilation). The

Table 1. Gas stove oven emission rates (μg/kcal)

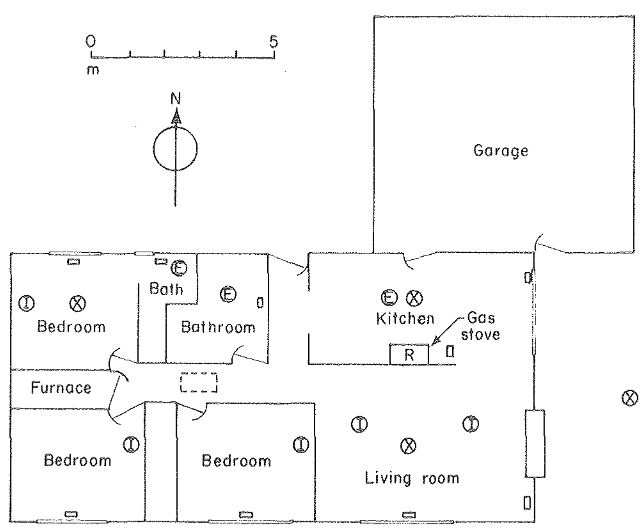
Pollutant	Lawrence Berkeley Laboratory		The Research Corporation of New England (TRC)[a]		British Gas Corp.	American Gas Assn. Standard
	Oven at 180°C (350°F)		Old Oven	New Oven	Oven	Oven
Gaseous Emissions						
CO	950(650-1500)[b]	[6][c]	530	1620		645
CO_2	200,000(195,000-205,000)	[6]				
NO	29 (14-50)	[11]	91.4	77.9	85 (NO + NO_2)	
NO_2	62 (44-74)	[11]	73.1	50.4		
SO_2	0.8 (0.5-1.0)	[11]				
HCN	1.8	[1]				
HCHO	11.4 (9.9-14.2)	[5]				
Particulate Emissions (< 2.5 μm)						
Carbon	0.13 (0.05-0.24)	[9]				
Sulfur (as $SO_4^{=}$)	(<0.01)	[9]				
kcal/hr	2000		2200	2200		

a. Steady-state emission rate
b. Range of emission rates in parentheses
c. Number of experimental runs in brackets

Table 2. Gas stove burner emission rates (μg/kcal)[a]

Pollutant	Lawrence Berkeley Laboratory		British Gas Corporation	American Gas Association Standard
Gaseous Emissions				
CO	890(720-1090)[b]	[4][c]		645
CO_2	205,000(196,000-217,000)	[3]		
NO	31(21-47)	[4]	136 (NO + NO_2)	
NO_2	85(69-100)	[4]		
SO_2	0.8(0.6-0.9)	[4]		
HCN	0.07	[1]		
HCHO	7.1 (3.6-10.5)	[2]		
Particulate Emissions ($<2.5\ \mu m$)				
Carbon	0.90(0.86-0.96)	[4]		
Sulfur (as $SO_4^{=}$)	0.05 (0.01-0.08)	[4]		
Total Respirable Mass	1.7 (1.0-2.6)	[3]		
kcal/hr. burner	2500		2500	

a. Operated with water-filled and cooking pots
b. Range of emission rates in parentheses
c. Number of experimental runs in brackets



⊗ = Air quality sampling points

Ⓔ = Heat exchanger exhaust sites

Ⓘ = Heat exchanger inlet sites

Ⓡ = Range hood

Fig. 1. Energy Efficient Buildings research house (XBL 7910-4489)

other is a heat-exchanging ventilation system which contains a cross-flow air-to-air heat exchanger;[4] the latter provides whole-house ventilation, as does infiltration. Air is exhausted out of the house from the kitchen and both bathrooms; outside air is injected into the living room and all three bedrooms.

Air quality was monitored from the kitchen, the living room, a bedroom, and one outdoor location. Gaseous pollutants (carbon monoxide, carbon dioxide, nitrogen oxide, nitrogen dioxide, and formaldehyde) were measured by drawing air from all monitoring sites to our array of instruments in the Mobile Atmospheric Research Laboratory (MARL).[5] The respirable fractions of particulates were also collected at each monitoring site and analyzed for total carbon, the primary element of particulate emissions from gas stoves. Temperature and dew point measurements were also made at each location.

With the aid of a study conducted by the American Gas Association in 1974,[6] we devised a typical gas stove consumption pattern to simulate actual cooking. These calculations yielded gas consumption values of 0.170 m^3 (6 ft^3) for both the breakfast and lunch meals and 0.425 m^3 (15 ft^3) for the dinner meal. Table 3 shows the results of the experiment for NO_2 and CO. No mechanical ventilation was used during the

Table 3. NO_2 and CO concentrations in EEB research house.

	NO_2 (ppm)	CO (ppm)
Peak 1-hour average		
Kitchen	0.452	24.2
Living Room	0.396	21.0
Bedroom	0.235	15.5
Outside	~0.07	0.4
24-hour average		
Kitchen	0.074	5.1
Living Room	0.073	5.1
Bedroom	0.045	4.1
Outside	0.035	0.4
Air exchange rates (air changes per hour-ach)		
morning	0.43	
mid-day	0.33	
evening	0.34	

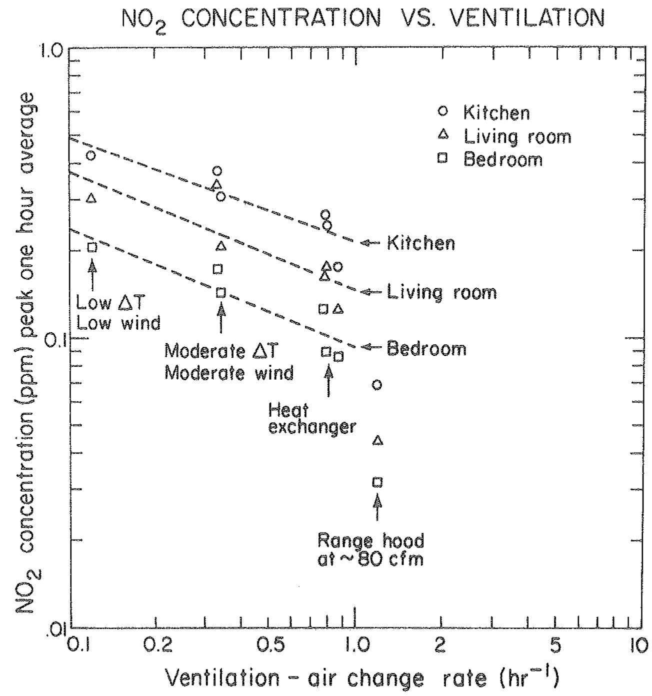


Fig. 2. NO_2 concentration vs. ventilation. (XBL 7910-4476)

experiment and natural infiltration varied between 0.33 and 0.43 air changes per hour (ach). As expected, the peak one-hour average pollutant concentration occurred during the dinner meal. The one-hour NO_2 air-quality standard proposed by the Environmental Protection Agency (EPA) is 0.25 ppm. As shown, NO_2 levels in both the kitchen and living room exceed this standard and in the bedroom, NO_2 levels are just under this limit. The one-hour EPA standard for CO is 35 ppm, and this limitation was not exceeded anywhere in the house.

Because of increasing concern about short-term exposure to elevated levels of NO_2, we tested various ventilation strategies based on our simulation of air-quality conditions during the dinner meal. Figure 2 shows the results of our first set of experiments. The dotted lines represent data points obtained under whole-house ventilation conditions. Although only one set of data is shown for spot ventilation, the advantage of such ventilation can be readily seen. For example, if we were to increase the whole-house ventilation rate to 1.2 ach, we would expect a peak one-hour average NO_2 concentration of about 0.20 ppm in the kitchen; however, by incorporating spot ventilation at the same rate, the peak one-hour average NO_2 concentration was reduced to 0.07 ppm.

These results suggest that an effective energy-conserving strategy for ventilating high levels of gaseous pollutants from a point source (e.g., the gas stove) would be to increase the rate of spot ventilation at the pollutant emission source rather than to increase whole-house ventilation, which can be costly.

Pollutant dispersion throughout the house was also measured under air-quality conditions simulated for the dinner meal. As shown in Table 4, NO_2 levels in the bedroom are one-half the kitchen levels, while CO levels in the bedroom are two-thirds the kitchen levels. The difference between the two ratios can be explained by the greater reactivity of NO_2 in the indoor environment.

PLANNED ACTIVITIES FOR 1980

Our research plans for FY 1980 are to complete the analysis of the data collected at the EEB research house, and to then concentrate on three additional areas: First, we will attempt to use data already collected at the EEB research house for testing, evaluating, and improving various models of indoor air quality in residences. Several models have been published but were either not tested or yielded inadequate predictions of indoor air. Second, we intend to further characterize particulate emissions from the gas stove focusing on the chemical form of carbon--the primary element

Table 4. Pollutant dispersion in EEB research house.

(Peak 1-hour exposures averaged over 8 experiments)

	NO_2	CO
Kitchen*	100	100
Living Room	77	82
Bedroom	53	68

*Indexed to equal 100

emitted--and the composition of the remaining particulate emissions. Third, we will attempt to develop a comprehensive passive-monitoring package to determine one-week average pollution levels in various building types. Such a system would allow us to conduct extensive field studies at minimal costs for instrumentation and personnel. Field studies would have the dual goals of testing a wide variety of building types (using different ventilation schemes) and determining actual pollutant levels to which occupants are exposed in the various indoor environments.

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ORGANIC CONTAMINANTS

R. R. Miksch, D. W. Anthon, M. Barnes, L. Z. Fanning, J. Glanville, H. Schmidt, and M. Tashima

INTRODUCTION

The Organic Contaminants Project of the Ventilation Program is currently investigating the pollution of the indoor environment by organic vapors. Research is being actively conducted in several areas; principally: (1) development of laboratory techniques for analyzing formaldehyde levels; (2) development of general methodologies for identifying and characterizing a wide variety of organic contaminants; and (3) development and implementation of a field monitoring program for measuring organic contaminants in indoor environments.

Studies by LBL[1] and others[2-4] clearly show that the levels of organic contaminants in indoor environments often exceed those encountered outdoors. Organic contaminants derive from a variety of sources: formaldehyde can be emitted from common building materials such as plywood, particle board and foam insulation (all of which contain urea-formaldehyde resins), and a wide range of organic contaminants are emitted from such materials as paints or adhesives as well as from combustion processes associated with occupant behavior.

It is generally accepted that the build-up of organic compounds in indoor environments can have adverse effects on the health of building occupants. Organic compounds such as aromatic and chlorinated hydrocarbons that we have encountered in field tests are capable of inducing acute toxic effects when present in high concentrations and, at lower levels of exposure, have been implicated in the etiology of cancer. In addition, we have detected indoor levels of formaldehyde that exceed European standards for safe exposure limits.

Although methodologies exist for sampling outdoor air or occupational indoor air and for performing subsequent analysis in the laboratory, present capabilities are somewhat limited with respect to sensitivity and the range of compounds that can be identified. At low concentration levels, numerous contaminants are difficult to measure quantitatively with any precision, and instruments for continuous monitoring of organic contaminants in indoor environments do not exist.

A major objective of the Organics Project has been to develop an overall methodology that will encompass both field sampling and laboratory analyses, and be readily transmissable to all those involved in studying or monitoring indoor air quality.

ACCOMPLISHMENTS DURING 1979

Development of Methods of Analysis

During 1979, the laboratory capabilities of the Organics Contaminants Project were expanded. A second Varian 3700 gas chromatograph and two Nutech thermal desorption devices were purchased. Laboratory space, which had been constricted, was expanded with the acquisition of a new room. Several personnel were added to the project. These improvements have greatly facilitated the accomplishment of the project tasks discussed below.

Several improvements have been effected in the design of field-sampling instruments for formaldehyde measurements. Air is now drawn through bubblers constructed from straight teflon tubing impingers and polypropylene centrifuge tube bodies. Not only are we now observing lower and more uniform pressure drops across these bubblers but accurate flow control is more easily obtained now that sintered glass frit impingers are not used. In addition, we have found that pooling the contents of two bubblers in series for each sampling line insures a higher and more uniform collection efficiency.

The bubblers have been placed in refrigerators where constant collection efficiency is better maintained and the stability of the samples and of reagents, such as MBTH, are enhanced. Field monitoring work also has been facilitated by these procedures, for not only can we now avoid such mishaps as bubblers going dry under low humidity conditions, but we can store samples for later analysis in the laboratory.

The two formaldehyde field samplers used by the EEB Mobile Laboratory continue to employ the very accurate air flow control system developed at LBL last year. Four other field samplers used for this work utilize critical orifices for flow control. By reducing the size and complexity of these samplers, we have been able to construct them as stand-alone units, i.e., not requiring the support of the EEB Mobile Laboratory. These design features also permit us to use samplers in a wider variety of sampling applications. Details of construction on both kinds of samplers are given in Fig. 1.

The Organics Contaminants Project staff has continued its comparison of various wet chemistry techniques for measuring formaldehyde and total aliphatic aldehydes. A major step forward has been our discovery that the health hazards associated with the pararosaniline technique can be greatly reduced by eliminating the toxic mercury reagent. Coupled with optimization work accomplished to increase the sensitivity of the pararosaniline technique, this method appears to LBL personnel to be superior to the chromotropic acid method given by the National Institute of Occupational Safety and Health (NIOSH) for determining formaldehyde.[5]

Having successfully perfected field-sampling instruments and methods of analysis, the Organics Project is now investigating further ways to improve our ability to measure and analyze formaldehyde levels in indoor environments. Two possibilities are being considered: the use of passive monitors with an appropriate collection medium, and the direct determination of formaldehyde by gas chromatography using an appropriately chosen detector. These two techniques would complement each other for extensive field studies. Significant formaldehyde levels identified through surveys conducted with passive

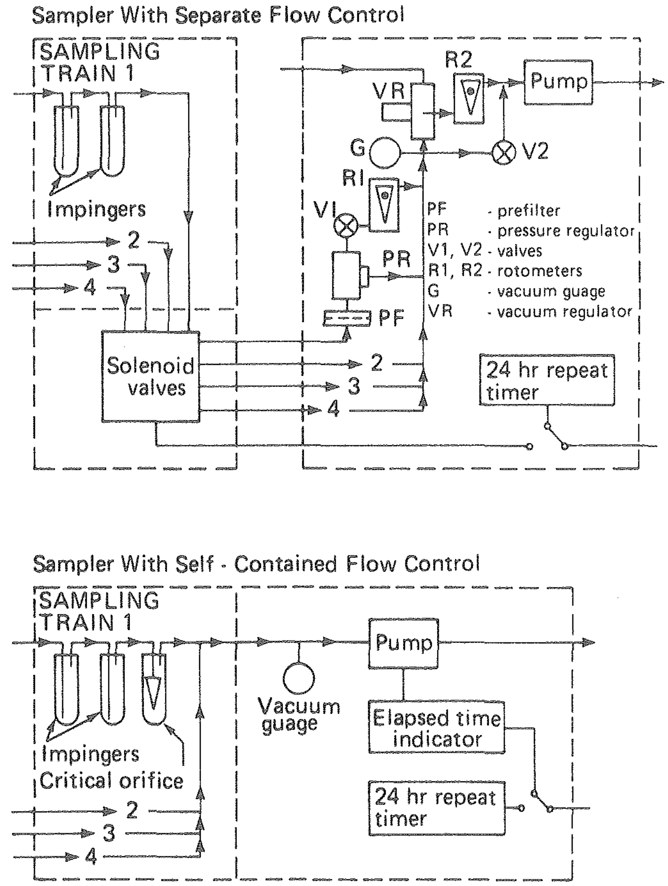

Fig. 1. Schematics of formaldehyde field samplers. Portion inside box labeled SAMPLING TRAIN 1 is contained in refrigerator. (XBL 7910-4484A)

monitors could be quickly validated using the gas chromatograph.

Another aspect of our work this year has been the continued investigation of a sampling and analysis methodology for organic contaminants based on the use of the porous polymer adsorbent, Tenax GC. In this method, field samples are taken by passing air through a glass tube containing Tenax GC. The tube is placed in a screw-top culture tube that is shipped to the laboratory where the sample is analyzed using a Nutech thermal desorption device in conjunction with a Varian 3700 gas chromatograph. The Nutech apparatus contains an oven which is used to thermally desorb organic contaminants from the Tenax GC contained in the glass tube into a cryogenic trap that reconcentrates the organic contaminants. The cryogenic trap is subsequently heated and the organic contaminants are introduced on to the gas chromatograph for separation and quantitative analysis. Figures 2 and 3 show representative gas chromatographs for outdoor and indoor air sampled at an LBL office trailer.

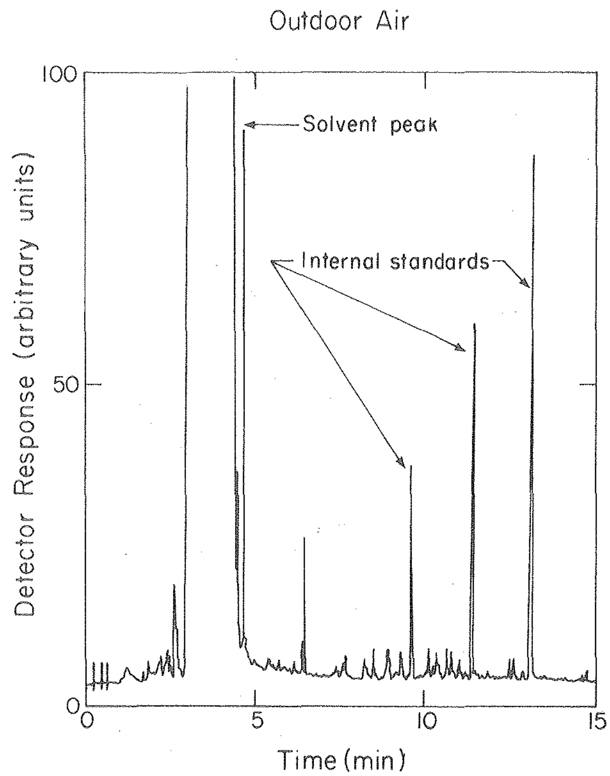

Fig. 2. Representative gas chromatograph showing number and concentration of organic contaminants collected from an outdoor air sample on the porous polymer Tenax GC. The size of the air sample is identical to that in Fig. 3. (XBL 7910-4474)

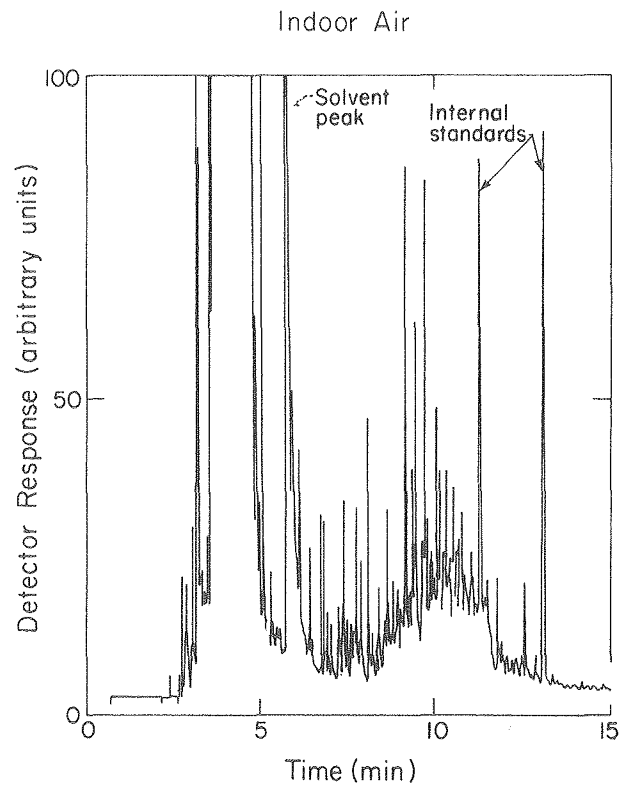

Fig. 3. Representative gas chromatograph showing number and concentration of organic contaminants collected from an indoor air sample on the porous polymer Tenax GC. The size of the air sample is identical to that in Fig. 2. (XBL 7910-4473)

The Nutech thermal desorption device has the advantage of being easily detachable, making it possible to reattach it to a Finnigan 4023 GC/MS available at LBL. The Finningan mass spectrometer allows us to positively identify many of the organic contaminants contained in a field sample. Once identified, contaminants can be quantified by means of gas chromatography to produce a detailed profile of the organic contaminants present in indoor environments.

A field sampling program using Tenax GC does have limitations, especially for analyzing low molecular weight compounds. We are currently working on alternate approaches such as merely taking a representative grab sample of air in an appropriate container. The use of alternative adsorbents and the possiblility of bubbling air through organic solvent are being explored.

Field Monitoring of Organic Contaminants

As a continuing part of the Ventilation Program's field monitoring project, formaldehyde and total aliphatic aldehydes were measured this year at the Fairmoor School in Columbus, Ohio, at the NAHB energy Research House in Carrol County, Maryland, and at a Minimum Energy Dwelling (MED II) in Mission Viejo, California.

The data from the Fairmoor School is presented in Fig. 4 in the form of a histogram. As a 20-year old structure, it is not surprising that the indoor concentration of formaldehyde did not vary significantly from ambient outdoor levels, even when air exchange rates were varied from about 2.5 ach (air changes per hour) down to 0.3 ach.

Measurements performed at the NAHB house in Maryland, as shown in Fig. 5, are considerably more interesting. This unoccupied, low ventilation (0.2 ach) house had indoor formaldehyde levels averaging about 80 ppb. The ambient air exposure level recommended in the United States is 100 ppb and an indoor air exposure level of 100 ppb has been recommended or promulgated in several European countries. It is interesting to note that total aliphatic aldehydes in the Maryland house, as determined by means of the MBTH method, averaged somewhat greater than 100 ppb. Outdoor concentrations were less than 10 ppb in both cases, clearly characterizing formaldehyde as an indoor pollutant.

Data taken at the MED-II house in Mission Viejo (see Table 1) are the most interesting of all because they clearly show that furniture and human occupants can be significant sources of indoor formaldehyde. When the house did not

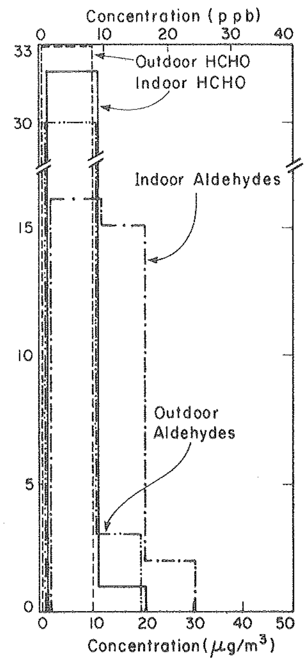

Fig. 4. Histogram of indoor and outdoor formaldehyde and total aliphatic aldehyde concentrations measured in a classroom of Fairmoor School, a 20-year old structure in Columbus, Ohio, during January and February, 1979. The air exchange rates of the classroom were varied from about 2.5 down to 0.3 ach during these measurements. The concentration of HCHO did not vary significantly with air exchange rate. (XBL 796-1748)

contain furniture, formaldehyde levels were below the standard exposure level of 100 ppb; when furniture was added, formaldehyde levels rose to almost twice the 100 ppb level. A further increase was noted when the house was occupied, very likely because of such activities as cooking with gas. When occupants opened windows to increase ventilation, the formaldehyde level dropped substantially. Under all of the conditions noted above, indoor formaldehyde levels were considerably in excess of ambient outdoor levels, which averaged less than 10 ppb.

Preliminary sampling of organic contaminants using Tenax GC was also performed at two sites, an LBL office trailer (90G) and a new San Francisco office building. As the Nutech thermal desorption devices were not available at the time, samples were prepared for gas chromatography/mass spectrometry (GC/MS) analysis by thermal desorption into a small quantity of organic solvent. The solvent was injected by syringe into the GC/MS in order to identify organic contaminants. The results of these tests are displayed in Table 2. The compounds identified fell into three broad categories: (1) aliphatic hydrocarbons; (2) alkylated aromatics; and (3) chlorinated hydrocarbons. Several of these compounds have been identified by the Environmental Protection Agency as "priority pollutants." A smaller number are suspected carcinogens (e.g., benzene). Estimates of concentrations, while necessarily tentative at this stage, invariably showed high indoor-to-outdoor ratios. While preliminary, these findings highlight the urgency of fully assessing the scope and magnitude of organic contaminants in indoor environments.

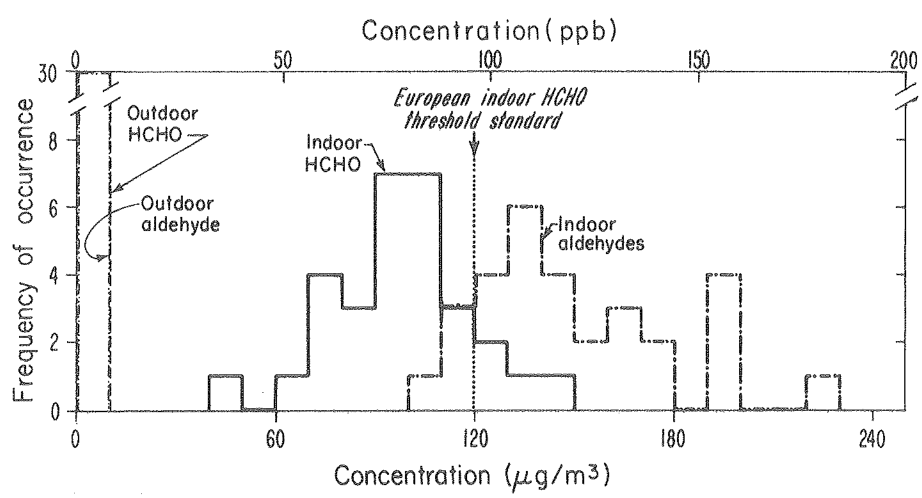

Fig. 5. Histogram of indoor and outdoor formaldehyde and total aliphatic aldehyde concentrations measured at an energy research house in Maryland during March and April, 1979. The air exchange rate of the house is about 0.2 ach. (XBL 795-1458A)

Table 1. Indoor/outdoor formaldehyde and aliphatic aldehyde concentrations measured at the Med-II residence, August 1979

Condition	Number of Measurements	Sampling Time	Formaldehyde (ppb)[a]	Aliphatic Aldehydes (ppb)[b]
Unoccupied, without furniture	3	12	66 ± 9%	74 ± 16%
Unoccupied, with furniture	3	24	183 ± 7%	241 ± 4%
Occupied, day[c]	9	12	214 ± 10%	227 ± 15%
Occupied, night[d]	9	12	115 ± 31%	146 ± 29%

a Determined using pararosaniline method (100 ppb ≅ 120 μg/m^3). All outside concentrations < 10 ppb.

b Determined using MBTH method, expressed as equivalents of formaldehyde. All outside concentrations < 20 ppb.

c Air exchange rate ≅ 0.4 ach.

d Windows open part of time; air exchange rate significantly greater than 0.4 ach and variable.

Table 2. Organic compounds identified in indoor air.[a]

Compound	Approximate Ratio [Indoor] / [Outdoor]	Approximate Concentration (ppb)	Agency Identifying Compound as Potential Health Hazard
Hydrocarbons:			
n-heptane	10	20	
n-octane	80	300	
n-nonane	100	150	
cyclohexane			
hexane			
many other branched aliphatics			
Aromatics:			
benzene	5	25	EPA, NIOSH, OSHA
toluene	5	75	
xylenes	15	150	
trimethylbenzene			
ethylbenzene			
ethylmethylbenzene			
Halogenated Compounds:			
tetrachloroethylene		large	EPA
trichloroethylene		small	EPA, NIOSH
1,1,1 trichloroethane		small	EPA, NIOSH

[a]Compounds identified were present in air sampled at an LBL office trailer (90G) and/or a San Francisco office building. Numerical data is for the San Francisco office building only.

PLANNED ACTIVITIES FOR 1980

The experimental studies planned for FY 1980 are contained in the various projects already mentioned. With sampling and analytic techniques for formaldehyde determination perfected, our emphasis will turn to examining wholly new approaches for radically increasing sensitivity, decreasing sampling time or increasing sampling capability. The organic sampling methodology based on Tenax GC will continue to be developed, with particular focus on techniques of calibration and field sampling. Alternative techniques, e.g., grab sampling, will be explored.

We will continue to work with the EEB Mobile Laboratory for field monitoring studies of energy efficient buildings throughout the country. Several sites will be added to those currently under investigation, and efforts will be made to correlate specific construction details (e.g. building materials used) and the use of air-to-air heat exchangers with organic contaminant levels.

Finally, we intend to examine explicitly the outgassing of organic contaminants from building materials. Using the methods of analysis developed for field samples, we will identify and quantify the organic contaminants in the headspace vapor over selected building materials and correlate these findings with field-sampling measurements.

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RADON MEASUREMENTS AND EMANATION STUDIES

J. V. Berk, M. L. Boegel, J. G. Ingersoll, W. W. Nazaroff, B. D. Stitt, and G. H. Zapalac

The main objective of the Radon Project is to determine the extent to which radon is a contaminant of indoor air in residential buildings. To this end, the program has undertaken three distinct areas of activities:

1. Monitoring conventional and energy-efficient residential buildings for radon levels;

2. Measurement of emanation rates of radon from building materials;

3. Development of appropriate monitors for detecting radon and radon daughters.

Radon-222, an inert gas, is part of the uranium-238 decay chain and, consequently, occurs naturally in the environment. The health hazards associated with radon result from its four short-lived radon daughters, RaA, RaB, RaC and RaC′, all of which have half-lives of less than 30 minutes and two of which (RaA, RaC′) are alpha-emitters.[1] Airborne radon daughters, when inhaled, can be deposited in the lower respiratory tract. It is known that prolonged exposure to elevated levels of radon daughters is related to increased incidence of lung cancer.[2]

Because radon outgasses from soil and building materials, the concentration of radon and radon daughters may build up in indoor spaces. Other possible radon sources within a building are tap water and natural gas. The potential for radon gas emission from these sources depends to a great extent on the content of radium-226 in the medium (soil, building materials) or on the initial proximity of the medium (water, natural gas) to radium-226-bearing deposits, since radium-226 is the immediate precursor of radon-222 in the uranium decay chain.

When energy-conserving features designed to reduce infiltration of outside air are applied to residential buildings, radon levels as well as levels of other indoor air pollutants may increase. If, as is often presumed in risk-assessment studies, the incidence of cancer from radiation exposure is directly proportional to the dose received,[3] then such an increase in radon levels would result in a higher incidence of lung cancer. The recognition that radon poses a health hazard, generally, and that energy-conservation measures adopted in residential buildings may exacerbate the health risks to building occupants has made indoor air-quality studies a research priority.

For reference purposes, typical levels of radon in outdoor as well as indoor air at representative geographical sites are shown in Fig. 1. Guidelines for remedial action due to industrial contamination that have been adopted by the Atomic Energy Control Board of Canada[4] and guidelines recommended by the U.S. Environmental Protection Agency[5] fall within a range of 1 to 4 nanoCuries per cubic meter (nCi/m^3).

ACCOMPLISHMENTS DURING 1979

Monitoring of Residential Buildings

The principal focus of this part of the program has been the measurement of radon levels in both energy-efficient and conventional houses. We employed three types of measurements to monitor buildings for radon levels: grab-sampling of air, accompanied by measurement of ventilation rates; real-time measurement of radon, radon daughters and ventilation rates; and integrated measurement of radon. Occasionally, we used more than one type of measurement at the same site in order to cross-check the results.

Since the beginning of spring, 1979, we have been monitoring energy-efficient houses across the country for radon concentrations versus air-change rates and other building characteristics that may affect indoor air quality. Of the 16 energy-efficient houses, nine (all located in the New Mexico area) are solar houses. Measurements of radon levels were taken under "worst case" conditions, i.e., closing up the building for several hours prior to the measurement (see Fig. 2). If the radon source-term were the same for all houses, one would expect all the points to fall on a straight line with a 45^o slope in a log-log plot. Obviously, this is not the case.

In a corollary study, we monitored a number of conventional residential buildings in the San Francisco Bay Area from August through September, 1979, in order to compare findings with those obtained in energy-efficient buildings. These measurements were also taken under "worst case" conditions, as previously described. The results of this preliminary survey are shown in Fig. 3, which shows that the majority of the houses monitored had low infiltration rates. What is striking in these results, however, is that even in cases where the infiltration rate was low, radon levels were low, an indication of low radon source strength. It is possible that the very slight indoor/outdoor temperature differences characteristic of Bay Area summers or the lack of winds might be responsible for the low infiltration rates.[2] In any case, these findings should be taken as typical only for conventional houses in the San Francisco Bay Area during the summer.

The National Association of Home Builders (NAHB) house at Mt. Airy, Maryland, was selected for more extensive monitoring because, out of all the houses we measured, it showed the highest radon levels (see Fig. 2). A heat exchanger was installed in that house so that we could vary the ventilation rate and measure corresponding variations in radon levels continuously for two weeks (see Fig. 4). Similar

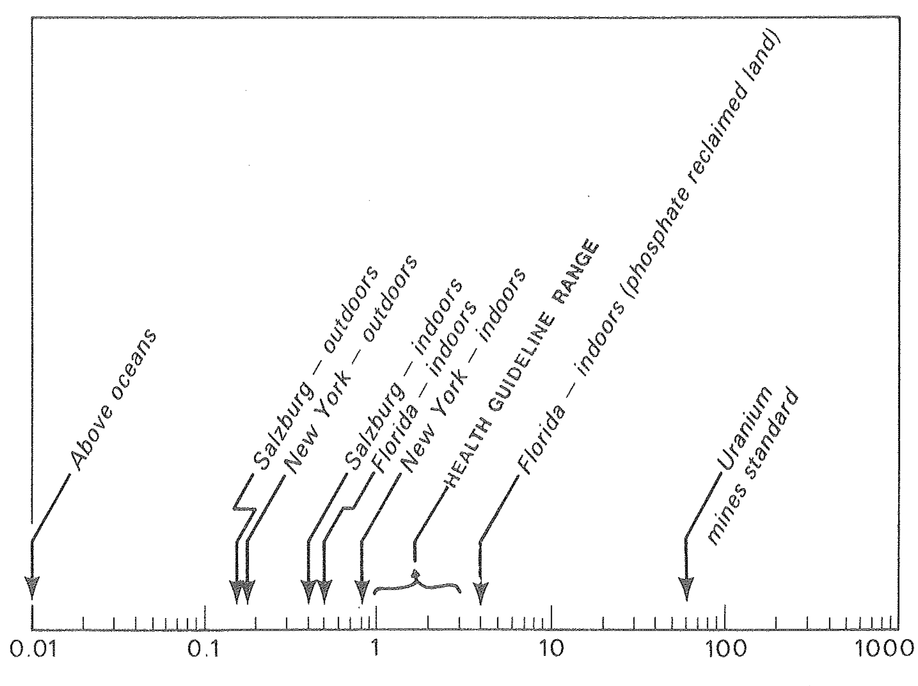

Fig. 1. Typical radon concentrations in air. (XBL 795-1659C)

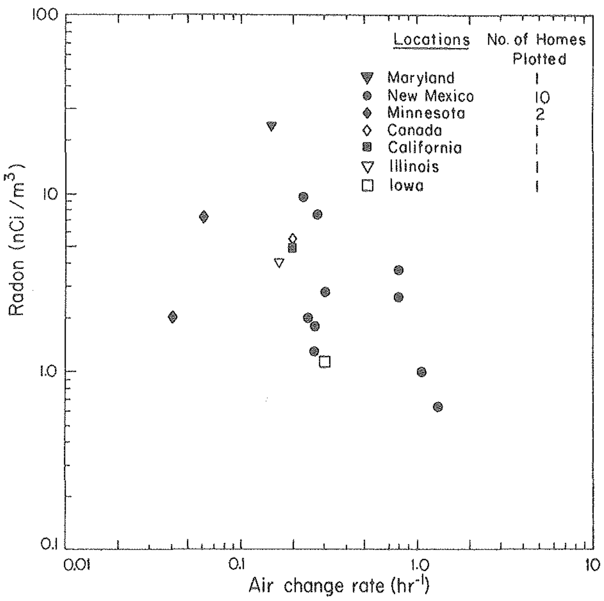

Fig. 2. Radon concentration vs. ventilation in energy-efficient houses. (XBL 796-1875A)

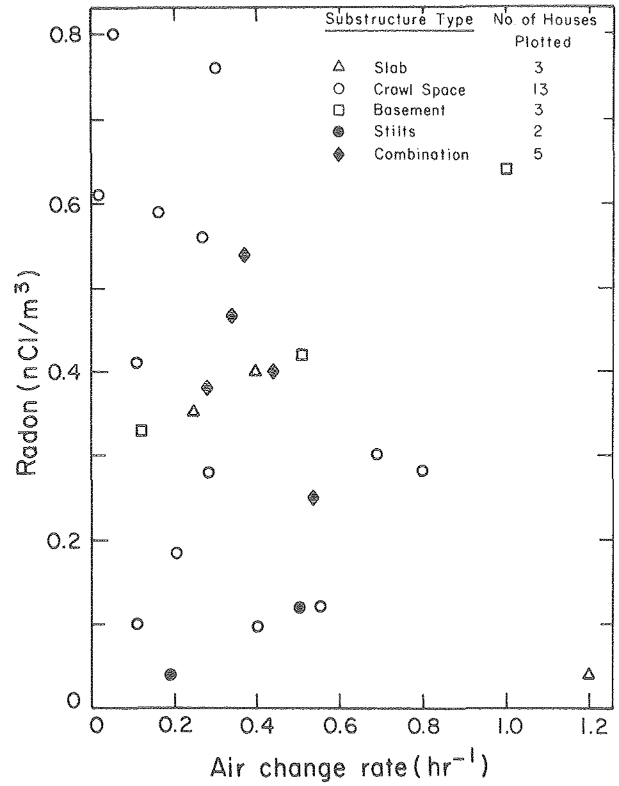

Fig. 3. Radon concentration vs. ventilation in conventional houses (San Francisco Bay Area). (XBL 799-7120)

measurements were taken for radon daughter concentration.

Measurement of Emanation Rates from Building Materials

A second major objective of the radon program is to measure radon emanation rates from building material samples from major population centers of the country and, from these data, to compile a listing of frequently used building materials in the U.S., estimating the relative significance of each as an indoor radon source. Concrete was the first building material considered.

A system for measuring radon emanation rates was under development in 1978 and was operative at the end of summer, 1979. The system is schematically shown in Figs. 5 and 6. The sample to be measured is allowed to remain for 24 hours in a sealed chamber, which is a modified paint can. The chamber is then flushed with helium (He) for one hour and the radon is collected by adsorption on glass wool at liquid nitrogen (N_2) temperature (-196°C). The glass wool trap is evacuated of non-condensed gases while kept at this temperature. It is then left to reach room temperature, at which the radon desorbs from the glass wool surface. Subsequently, the radon is transferred from the trap to a Lucas cell using He as a carrier gas. The emanation rate of the sample is determined by counting the alpha-decay rate of radon and its

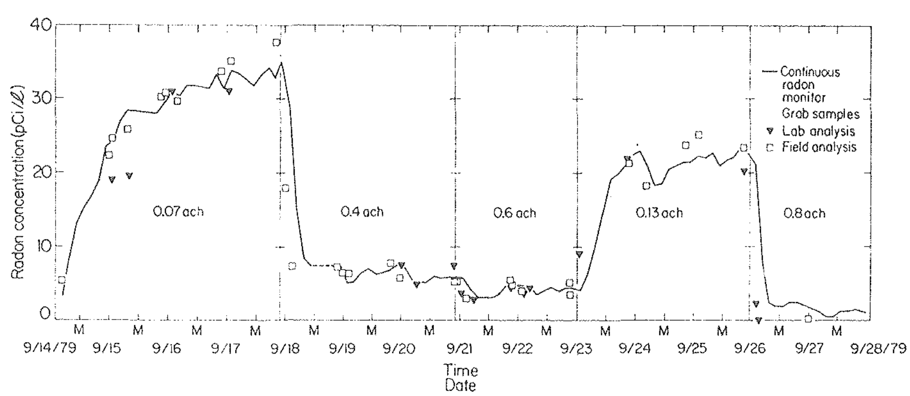

Fig. 4. Indoor radon concentration vs. ventilation rate controlled by a heat exchanger in the NAHB house over a two week period. (XBL 790-4440)

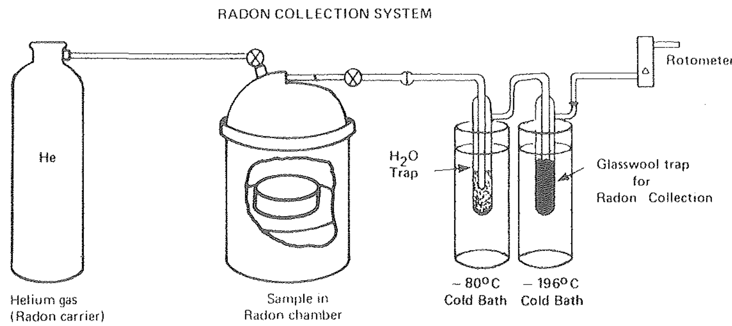

Fig. 5. Radon emanation and collection system. (XBL 793-859A)

daughters in the Lucas cell. For calibration, standard radium solutions supplied by the National Bureau of Standards provide radon sources of known strength.

The uncertainty in the emanation measurement ranges from 5% to 15%, depending on the sample. This system, of course, is designed to handle any building material sample. To date, we have built eight radon chambers so that several samples can be measured simultaneously. The concrete samples we have been using are standard American Society for Testing and Materials (ASTM) cylinders (6" in diameter, 12" in height) provided to us by various concrete testing laboratories. Between 6 and 12 cylinders are received from each site.

Each cylinder is cut into 1" and 10" pieces and both pieces are measured for radon. The 10" piece emanates approximately (within 5% to 10%) ten times as much as the 1" piece. This feature enables us to estimate the amount of radon expected to emanate from building walls or slabs made out of the same material. Samples from the San Francisco Bay Area, California; Kansas City, Missouri; Salt Lake City, Utah; Albuquerque, New Mexico; Philadelphia, Pennsylvania; and New York City, New York have been measured already. Measured emanation rates per mass have been in the range of 0.5 to 2.0 pCi/kg.hr.

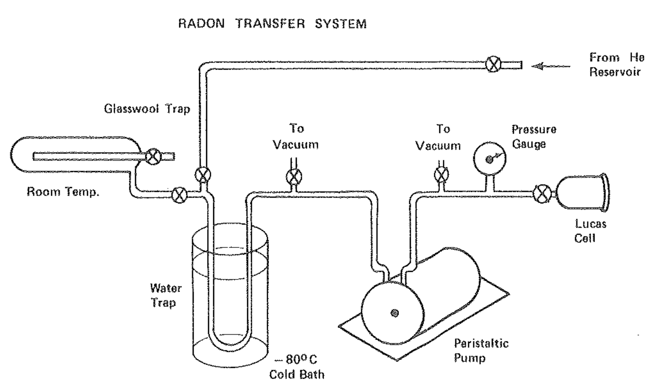

Fig. 6. Radon transfer system. (XBL 793-860A)

Once the emanation rate of radon from concrete has been determined, it is straightforward to calculate the indoor radon levels that can be expected from concrete alone in a typical residential building. As an example, in a house with 1800 $ft.^2$ floor area, 8 ft. height, a substructure consisting of a heavy concrete slab 8" thick, and a ventilation rate of 0.5 ach, the previous emanation rates would contribute 0.1 to 0.4 nCi/m^3 to the indoor radon level. Based on these laboratory measurements of emanation rates, we would conclude that the emanation of radon from the concrete is negligible compared with that measured in most houses.

Development of Monitors

Work on passive radon monitors has continued over from 1978, and active radon and radon daughter monitors were developed during 1979.

The 25 Passive Environmental Radon Monitors (PERMs) built in 1978[1] were extensively tested in our calibration box. A number of performance-hampering defects in construction were discovered and corrected, reducing their reproducibility error to less than 20%, including the error in the lithium fluoride TLD chip reading, which was of the order of 13%. Dysporsium-doped, calcium fluoride TLD chips have also been tested in an effort to increase the sensitivity of the instrument. The 25 PERMs are currently used routinely for conducting integrated measurements of radon in residential buildings, as described earlier. Plans for the fabrication of 50 additional PERMs, incorporating several new operational and engineering features deemed necessary from our past experience, are now underway.

For our work on active monitors, we have developed a radon monitor and a radon daughter monitor and have built a continuous monitor based on a prototype developed by others.[6] The continuous radon monitor is shown schematically in Fig. 7. Pre-filtered air, i.e., freed of all radon daughters, is continuously drawn into a two-port 170 ml scintillation flask (Lucas cell) at a rate of 2 liters per minute (lpm). A photomultiplier tube system is used to count the alpha-decays from the radon and the two alpha-emitting radon daughters in the cell. A printer

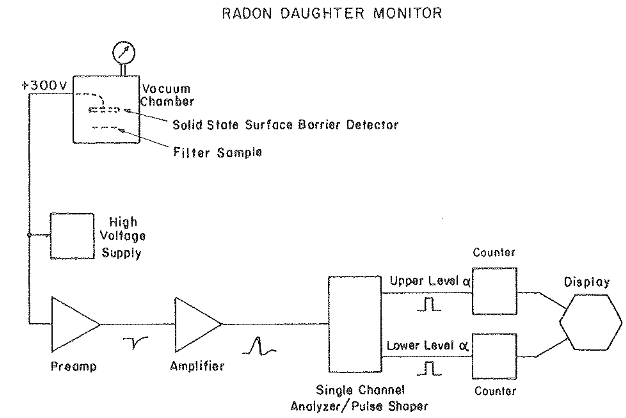

Fig. 7. Radon daughter monitor. (XBL 799-7119)

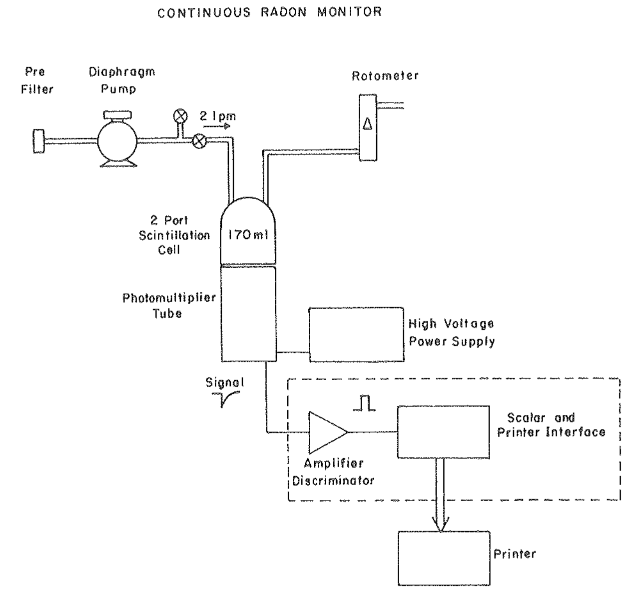

Fig. 8. Continuous radon daughter monitor. (XBL 799-7118)

is interfaced with the system so that total counts can be printed out over a pre-set time interval. (We have been using a time interval of 36.4 minutes.) A prototype of this instrument was built in August and has been used since then for field and laboratory measurements of radon concentrations.

The radon daughter monitor, shown in Fig. 8, was developed by members of the radon group. Radon daughters are collected on a teflon filter by drawing air through the filter at a rate of 10 to 15 lpm. After ten minutes of collection time, the filter is placed inside a chamber opposite a solid-state surface barrier detector and the chamber is evacuated to 5" of Hg, absolute. A single-channel analyzer discriminates and separately counts pulses from the two different alpha energies, 6.00 MeV and 7.69 MeV, of the alpha-emitting daughters, RaA and RaC′, respectively. In order to determine the nuclide ratio of the three daughters, RaA:RaB:RaC (RaC:RaC′=1 because of the extremely short half-life of RaC′) and from that the corresponding Working Level (WL), two consecutive measurements of their alpha activity are necessary. At present, we take the first of the two consecutive measurements between 11 and 33 minutes from the beginning of the 10-minute collection time and the second between 35 and 50 minutes. These time intervals were determined by computer analysis to be optimal for assuring maximum instrument sensitivity as long as the total sampling and counting time does not exceed one hour. Within this time constraint, the radon daughter monitor can measure as low as 0.0025 WL with an error of 10%. The uncertainty in the measurement of each of the daughters is 20% at 1.0 nCi/m^3. A prototype of this monitor, also built in August, was used for the radon daughter studies conducted at the NAHB house in Maryland in September, 1979.

PLANNED ACTIVITIES FOR 1980

In 1980, the radon program will continue the field monitoring of energy-efficient houses across the country, including solar houses in New Mexico and possibly California. We will also continue monitoring conventional houses in the San Francisco Bay Area as well as elsewhere in the U.S. In all cases, field monitoring will involve measuring both radon and radon daughters.

We plan to complete our measurements of radon emanation rates from concrete samples representative of all major metropolitan areas of the country. Later on, other building materials (bricks, gypsum) may be measured for radon emanation rates.

In the area of instrumentation, we will continue to work on improving active and passive monitors for radon and radon daughters.

Finally, we plan to examine some active and passive radon control strategies.

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INDOOR RADON HEALTH RISKS

A. V. Nero

INTRODUCTION

Radon-222 and its daughters, members of the uranium-238 decay chain present throughout the earth's crust, have long been recognized as significant contributors to natural background radiation. Exposure of the general population to radon and daughters occurs primarily indoors, where concentrations are usually higher than outdoors. While not all energy efficient or retrofitted buildings have low air-exchange rates, a reduction in ventilation rate may result in an increase of indoor radon levels. The purpose of this project is (1) to evaluate the health impact of radon and its daughters as indoor air pollutants and (2) to examine the significance of indoor radon in energy-efficient buildings that are designed (or retrofitted) to reduce infiltration or ventilation. This project is being carried out in close collaboration with the Energy Efficient Buildings Radon Program, which is performing indoor radon measurements and developing monitoring instrumentation.

A basic aspect of assessing health risks of a substance is to determine the dose-response relationship between exposure and increased incidence of disease or pathology. In the case of radon and its daughters, findings that the incidence of cancer is greater among uranium and other miners than among the general population has been correlated with the prolonged exposure of these miners to high radon levels.[1] If the dose-response factor is extrapolated from data on miners and applied to populations exposed to lower radon levels, we can estimate that continuous exposure to 1 picocurie per liter (1pCi/l) of radon and a typical amount of associated daughters would contribute a lung cancer incidence of as much as 100 per million per year, a significant fraction of the current incidence from all causes.[2] This estimate is highly uncertain, since it is based on an extrapolation from high to low doses as well as on other assumptions (e.g., exposure conditions--mines vs residences). However, judging from limited data available on indoor radon concentrations, the estimate of 1 pCi/l is probably within a factor of two of the average value for residences in the United States. Moreover, on the basis of existing data, it appears that a significant portion of conventional residences in areas of the United States that are naturally high in radium have considerably higher radon concentrations than 1 pCi/l. When air-exchange rates are reduced, as occurs in energy-saving retrofits, indoor radon levels would be even more elevated. Reducing air exchange rates in such houses, or building energy-efficient houses in such areas, may subject occupants to unacceptably high individual risks.

There are, thus, two important aspects to limiting radon and radon daughter levels. One is to limit individual risk by setting numerical limits on indoor radon or daughter concentrations. The second is to develop broad radon control strategies, including a spectrum of control measures for energy-efficient buildings, that would constrain the average increase (if any) in radon exposure to an acceptable level.

PLANNED ACTIVITIES FOR 1980

We have considered these two viewpoints in examining the impact of increased radon levels for the Residential Conservation Service (RCS) program, which plans to provide low-interest loans nationwide for retrofitting existing homes. The RCS program, to be implemented in 1980, is not expected to have substantial impact on the average air-exchange rate in the nation's homes. This is fortunate since sufficient information is not available to undertake the comprehensive risk-benefit analysis necessary to determine "acceptable" increases in radon exposure. However, it is also clear that in a small percentage of homes affected, radon levels are already unacceptably high. We have therefore recommended that the RCS program include a screening procedure capable of identifying areas with unusually high radon levels so that infiltration-reducing measures would not be recommended in such cases -- at least not without detailed consideration of the impact of retrofits on radon levels and the suggestion of adequate control measures. (For geographical areas where radon levels are particularly high, we would anticipate that remedial measures would be implemented regardless of any RCS program measures affecting air-exchange rates.)

In order to assess the impact of energy-conservation programs on indoor air quality with respect to radon health risks, we will continue to work closely with the Building Energy Conservation Program on three general goals: 1) to assess, on the basis of available information, the health risks from indoor radon levels in existing, new, and retrofitted housing; 2) to indicate how to improve the available information so that it serves as a more adequate basis for risk assessment, and 3) to evaluate options for controlling the increased risk that may be associated with energy conservation measures and programs.

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FIELD MONITORING OF INDOOR AIR QUALITY

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In order to establish criteria for setting energy-efficient ventilation standards, the Ventilation Program staff is conducting a comprehensive assessment of indoor air quality in different types of buildings under a variety of ventilation conditions. Table 1 lists several indoor contaminants that have been identified as potential health hazards, and their sources. The Ventilation Program at LBL is measuring a number of these pollutants and developing techniques for sampling and measuring others.

As part of our ongoing field monitoring of indoor air quality, we have been measuring pollutant levels in prototype energy-efficient residential homes. We are also studying educational facilities and hospitals before and after energy-conserving retrofits are implemented.

Table 1. Indoor air pollutants in residential buildings.

SOURCES	POLLUTANT TYPES
OUTDOOR	
Ambient Air	SO_2, NO, NO_2, O_3, Hydrocarbons, CO, Particulates
Motor Vehicles	CO, Pb
INDOOR	
Building Construction Materials	
Concrete, stone	Radon
Particleboard, Plywood	Formaldehyde
Insulation	Formaldehyde, Fiberglass
Fire Retardant	Asbestos
Adhesives	Organics
Paint	Mercury, Organics
Building Contents	
Heating and cooking combustion appliances	CO, NO, NO_2, Formaldehyde, Particulates
Furnishings	Organics
Water service; natural gas	Radon
Human Occupants	
Metabolic activity	H_2O, CO_2, NH_3, Odors
Human Activities	
Tobacco smoke	CO, NO_2, Organics, Particulates, Odors
Aerosol spray devices	Fluorocarbons, Vinyl Chloride
Cleaning and cooking products	Organics, NH_3, Odors
Hobbies and crafts	Organics

Some of the specific parameters being measured by the Ventilation Program staff and LBL subcontractors are:

- temperatures and relative humidity
- odors
- toxic chemicals (gases and particulates)
- microbial burden

EEB Mobile Laboratory

The Energy Efficient Buildings (EEB) Mobile laboratory[1] was completed in 1978 to facilitate field studies of indoor air quality and energy utilization in buildings. The EEB Mobile Laboratory contains sampling, calibrating and monitoring systems that allow us to measure various contaminants of indoor air (see Table 2).

Air-exchange rates have been measured using a tracer gas system[2] developed at LBL in which nitrous oxide is injected and monitored continuously under controlled conditions at the sampling sites. A similar system using ethane as a tracer gas has recently been installed. Air exchange rates and the other continuously monitore parameters are recorded on a microprocessor-controlled floppy disk. The recorded information is transmitted back to LBL by telephone or by sending the floppy disks back to LBL where they may be read into our computer system.

The EEB Mobile Laboratory, shown in Exhibit 1, is positioned outside the building to be studied. Air from three different locations within the structure and from the outside is drawn through teflon sampling lines into the trailer for analysis. By sequentially sampling these lines, the indoor and outdoor air quality are monitored.

For pollutants whose concentrations are too low for direct measurement, such as particulates, formaldehyde, and radon, grab sampling techniques are used. The particulate matter in

Table 2. Instrumentation for Lawrence Berkeley Laboratory ventilation requirements system.

Parameter	Principle of Operation	Manufacturer/Model
Field		
Continuous Monitoring Instruments:		
Infiltration		
N_2O or C_2H_6 (Tracer gas)	IR	LBL
Indoor Temperature and Moisture		
Dry-Bulb Temperature	Thermistor	Yellow Springs 701
Relative Humidity	Lithium Chloride Hygrometer	Yellow Springs 91 HC
Outdoor Meteorology		
Dry-Bulb Temperature	Thermistor	Meteorology Research 915-2
Relative Humidity	Lithium Chloride Hygrometer	MRI 915-2
Wind Speed	Generator	MRI 1074-2
Wind Direction	Potentiometer	MRI 1074-2
Solar Radiation	Spectral Pyranometer	Eppley PSP
Metric Rain Gauge	Tipping Bucket	MRI 382
Gases		
SO_2	UV Fluorescence	Thermo Electron 43
NO, NO_x	Chemiluminescence	Thermo Electron 14D
O_3	UV Absorption	Dasibi 1003-AH
CO	NDIR	Mine Safety Appliances-Lira 202S
CO_2	NDIR	M.S.A. Lira 303
Radon	Alpha Dosimetry	LBL
Particulate Matter		
Size Distribution	Optical Scattering	Royco Particle Counter 225
Radon Progeny	Under Development	LBL
Sample Collectors		
Gases		
Formaldehyde Total Aldehydes	Chemical Reaction/Absorption (Gas Bubblers)	LBL
Selected Organic Compounds	Adsorption (Tenax GC Adsorption Tubes) for GC Analysis	LBL
Particulate Matter		
Aerosols (Respirable/Non-respirable)	Virtual Impaction/Filtration	LBL
Bacterial Content	Inertial Impaction	Modified Anderson Sampler
Data Acquisition System		
Microprocessor		Intel System 80/20-4
Multiplexer A/D Converter		Burr Brown Micromux Receiver MM6016 AA Remote MM6401
Floppy Disk Drive		ICOM FD3712-56/20-19
Modem		Vadic VA-317S

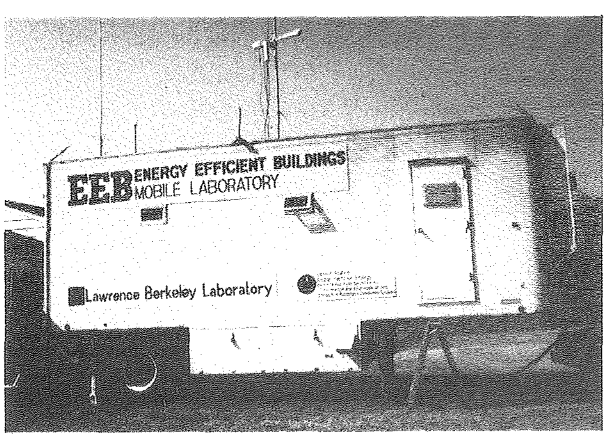

Exhibit 1. The EEB Mobile Laboratory.
(CBB 790-16251)

the sampled air is measured by automatic dichotomous air samplers[3] developed at LBL to separate aerosols into respirable and non-respirable fractions (below and above 2.5 micron size, respectively). This device uses a flow-controlled virtual impaction system which deposits the particulate matter on teflon filters. The particulates collected on the filters are analyzed by others at LBL using beta-ray attenuation to measure mass concentration, and X-ray fluorescence to determine chemical composition. Radon, formaldehyde, total aldehydes, and bacteria must be collected by means of gas bubblers and other sampling techniques and also require subsequent laboratory analysis.

ACCOMPLISHMENTS DURING 1979

During 1979, the mobile trailer was used to monitor indoor air quality at four field sites: the Fairmoor Elementary School in Columbus, Ohio (selected by the American Association of School Administrators as a target school for energy-conserving retrofits), "ERHM," (an energy research house in Carroll County, Maryland), MED-II (a production model minimum-energy dwelling in Mission Viejo, California) and Oakland Gardens Elementary School in Bayside, New York. Additional field monitoring, performed by subcontractors, is described later in this section.

Fairmoor School

The ventilation system at the Fairmoor School consists of a single-unit ventilator in the exterior wall of each classroom. Two gas-fired boilers in the school deliver hot water or steam to the unit ventilator in each classroom. The unit ventilator has a thermostatically controlled damper that determines the relative quantities of outdoor and recirculated air to be supplied to the room. Excess room air is vented into the corridor and discharged. For our purposes, manual override switches and a pneumatic control system were installed to control the ventilation rates in two classrooms and one large, multi-purpose room. With outside air supply rates adjusted down from approximately 6.5 cfm per occupant to 1.5 cfm per occupant, indoor air quality was monitored in these classrooms. For comparative purposes, outdoor air was simultaneously monitored.

Ventilation Rates and Chemical Indoor Air Quality

Carbon dioxide was the only pollutant found to exhibit significantly high concentrations inside the school, and the primary sources were the occupants themselves. Fig. 1 shows the frequency distribution of CO_2 concentrations at various ventilation rates in one of the classrooms. Data points sorted into bins along the horizontal axis represent ten-minute samples taken every forty minutes during regular school hours. Although CO_2 concentrations did increase inside the classrooms when ventilation rates were reduced, at no time did they exceed 4000 ppm, and only occasionally did they exceed 3000 ppm. (Occupational standards for CO_2 have been set at 5000 ppm and 10,000 ppm[4,5,6] and refer to time-weighted average concentrations for up to 10-hour workshifts in a 40-hour work week; studies indicate that workers may be exposed to these concentrations day after day without adverse health effects.[4])

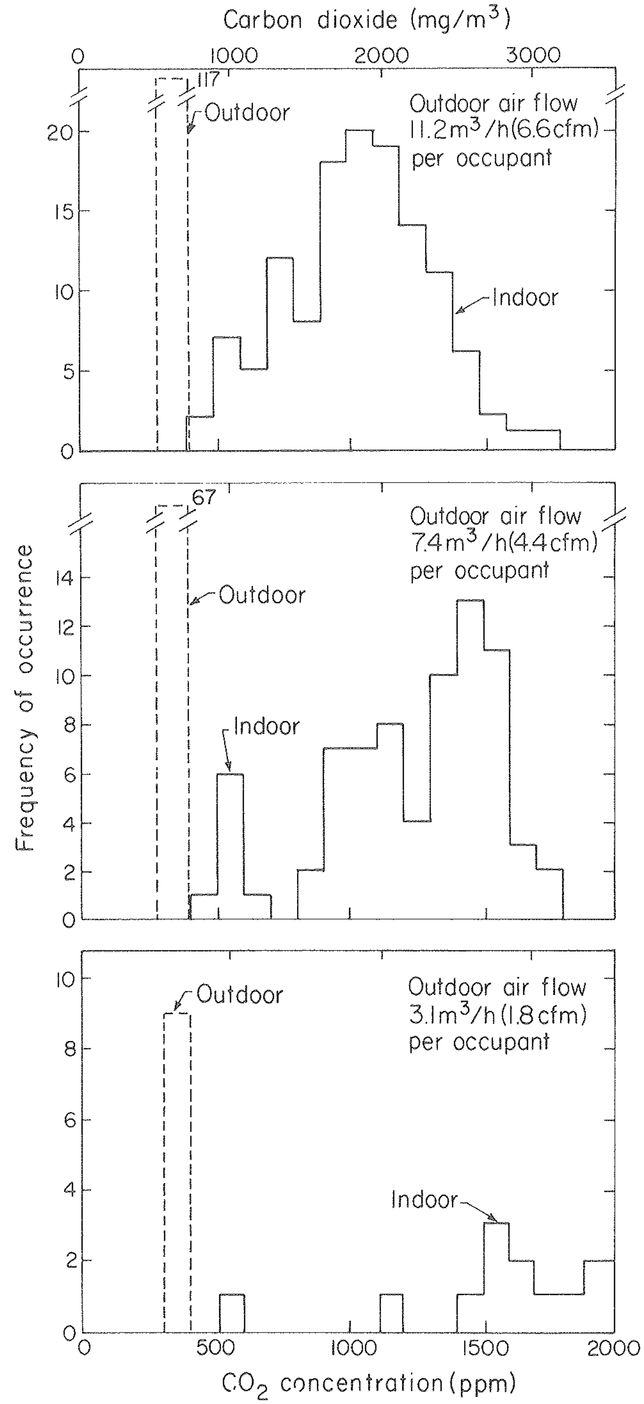

Fig. 1. Frequency distributions of CO_2 concentrations at Fairmoor Elementary School measured at 3 ventilation rates. The graphs represent data for school days only between 8:00 a.m. and 3:00 p.m. (XBL 7910-4429)

Ventilation Rate and Sensory Perception of Indoor Air Quality (The Research Corporation of New England)

The Fairmoor School was the first site visited by The Research Corporation of New England (TRC) as part of its field monitoring program to determine ventilation requirements for odor control in buildings. Under contract to LBL, TRC and its subcontractors performed two types of studies. In three buildings (one school, one hospital and one office building), the sensory perception of odors, odor acceptability and the chemical composition of indoor air was studied for a two-week period at both existing and reduced ventilation rates. For twelve other buildings (six schools and six hospitals), the sensory perception of odors and the chemical composition of indoor air were surveyed (for one day) at existing ventilation rates only.

All odor perception measurements were carried out in a mobile laboratory brought to the building site. Odor panelists were recruited from people in the area who are not regular occupants of the building. Air samples within the building are collected in 100-liter Tedlar bags and brought to the mobile trailer.

At all sites, the sensory perception of odors was measured in two ways. The first method employs a forced-choice triangle olfactometer (Exhibit 2) to determine the number of dilutions necessary to bring an odorous air sample to a level where 50% of the members of an odor panel no longer detect it (ED_{50}).[7] The olfactometer is equipped with five stations, four of which present dilution ratios of 81, 27, 9 and 3 and the fifth station, the undiluted odor. One glass sniffing port supplies the given dilution level progressing from weakest to strongest (undiluted) concentrations while the other two sniffing ports supply filtered outside air. For each of the five levels of concentration, the odor panelist indicates which of the three ports he or she believes delivers odorous air. Following this process, odor judges are presented with the undiluted odor and using a device called a butanol olfactometer (Exhibit 3) are asked to compare it with progressively increasing concentrations of butanol until a match is made between the intensity of butanol (in ppm) and the intensity of the undiluted sample.[8]

In addition to the procedures described above, both the odor panelists and building occupants filled out a questionnaire (Exhibit 4) twice daily on various "elements" of the room

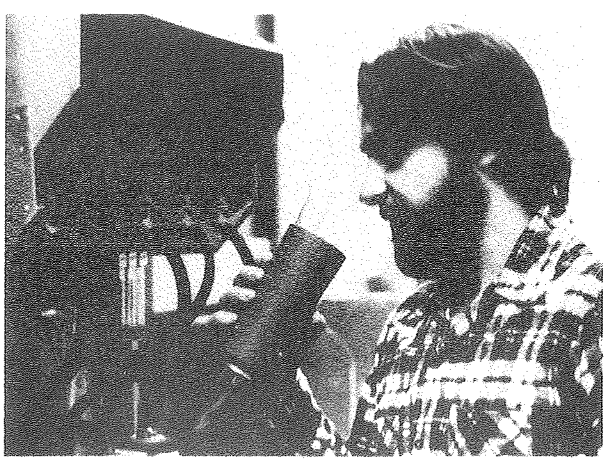

Exhibit 2. Subject using forced-choice triangle olfactometer. One of the three nozzles emits a diluted stream of air taken from the ventilation chamber. The other two nozzles emit pure air. The subject seeks to decide, by smell, which nozzle emits air from the chamber. (XBB 802-2681)

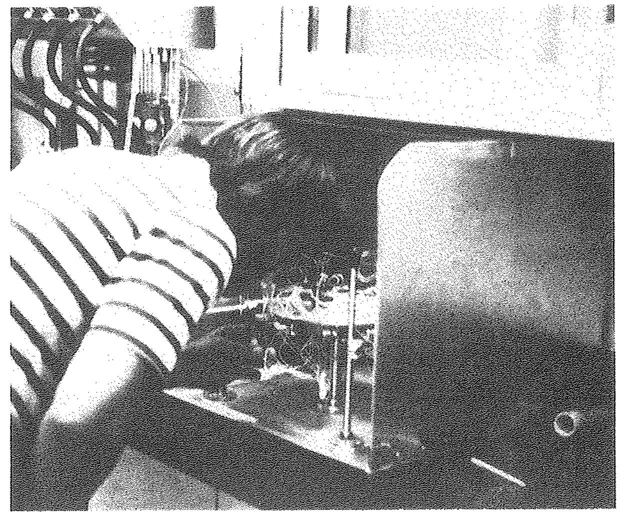

Exhibit 3. Subject using the butanol binary dilution olfactometer to find a level of butanol that matches the perceived intensity of the "occupancy odor" of an occupied ventilation test chamber. (XBB 802-2680)

environment, including odor level, all of which are rated on a nine-point scale. Each aspect of the environment is also rated for "acceptability".

Another aspect of the TRC study at these sites involved collecting air samples on porous polymers which were packed within tubes to facilitate later laboratory analysis for odorant composition. The chemical analyses were carried out by gas chromatographic and mass spectroscopic techniques.

Table 3 summarizes average odor dilution and odor intensity results for the three test rooms at the Fairmoor school at normal and reduced ventilation rates. The odor dilution ratio (ED_{50}) under normal ventilation conditions was close to the ED_{50} for outside air. At reduced ventilation rates, the ED_{50} doubled in the two classrooms and increased slightly in the gymnasium. The odor intensity, as measured by the butanol olfactometer, exhibited no statistically significant change when the ventilation rate was reduced. The occupants of these rooms found the odor level acceptable at all times; however, the acceptability as perceived by visitors to these rooms (odor panel) decreased in Room 12 under reduced ventilation rates and to a lesser degree in Room 20, where the ventilation rate reduction was somewhat less than in Room 12. The ASHRAE standard 62-73 for odor acceptability of outdoor air calls for agreement of at least 60% of a panel of no fewer than 10 untrained observers that the air is free of objectionable odors. If the present standard were applied to indoor air, the odor levels in the two classrooms where ventilation rates were reduced would have been classified as unacceptable. The outside air ventilation rate under sealed conditions, however, was below the minimum (5 cfm/person) established in ASHRAE Standard 62-73. Criteria for indoor air quality with

Day Number ________ Date ________ Time ________ Room Number ________

EVALUATION SHEET

Rating of Individual Elements of the Room Environment			Acceptable	Unacceptable
Cold	___:___:___:___:___:___:___:___	Hot	☐	☐
Humid	___:___:___:___:___:___:___:___	Dry	☐	☐
Drafty	___:___:___:___:___:___:___:___	Stuffy	☐	☐
Stale	___:___:___:___:___:___:___:___	Fresh	☐	☐
No odor	___:___:___:___:___:___:___:___	Strong odor	☐	☐
Loud noise	___:___:___:___:___:___:___:___	No noise	☐	☐

Overall Rating of the Room Environment

Acceptable ___:___:___:___:___:___:___:___ Unacceptable

1. Do you have a cold today?

   Yes ☐ No ☐

2a. If you are a smoker, about how many hours ago today did you have your last smoke?

   _____ hours ago

2b. If you are not a smoker or if you did not smoke today, check this box . . . . ☐

Exhibit 4. Questionnaire on indoor air quality.

Table 3. Summary of odor and ventilation data from Fairmoor Elementary School.

	Odor dilution ratio (ED_{50})		Odor intensity Butanol scale (ppm)		Average acceptability (%)	
	Normal vent.	Reduced vent.	Normal vent.	Reduced vent.	Normal vent.	Reduced vent.
Room 12						
a.m.	4	13	57	42		
p.m.	8	9	30	43		
Average	6	11	43	43	76.5	55
Room 20						
a.m.	6	14	50	46		
p.m.	6	10	43	55		
Average	6	12	47	50	67.6	56.3
Multipurpose Room						
a.m.	9	9	44	32		
p.m.	6	9	40	35		
Average	7	9	42	33	94	92

respect to odor levels are now being developed by ASHRAE.

The gas chromatographic mass spectroscopic (GS/MS) results indicate that the odorants collected in these classrooms derive from cleaning compounds, polishes and, perhaps, automotive exhaust, but not body odor; however, odorant concentrations were too low to allow positive identification by gas chromatographic odorogram analysis.

In summary, odorant concentrations are low at both normal and reduced ventilation rates; the occupants of the building find the odor level acceptable under both ventilation conditions; and visitors to the classroom sometimes find the odor level unacceptable at reduced ventilation rates (if acceptability is based on odor criteria for outdoor air.)

Ventilation Rates and Microbial Burden

The Naval Biosciences Laboratory was subcontracted by LBL to provide scientific and technical support to the ventilation group on sampling, assay, and data analysis of airborne bacterial content in educational facilities and hospitals where related field monitoring studies are being conducted. NBL was to determine whether energy-conserving changes in ventilation practices would lead to unacceptable levels of airborne microbes; to this end, data was to be analyzed both before and after retrofit.

During FY 1979, NBL performed measurements on airborne microbes at three sites: Fairmoor School, Long Beach Naval Hospital, and a San Francisco office building. (Data from the San Francisco office building are yet to be analyzed.) In addition, they conducted experimental aerosol studies to test filter effectiveness for microbial removal.

At Fairmoor School, instruments that measure airborne microbes[9] in six size ranges were placed in two classrooms and in a combination auditorium-gymnasium. Samples of airborne microbes were taken by NBL at 8:00 and 10:00 a.m. and at 1:00 and 3:00 p.m. The average number of colony-forming particles/cubic meter of air for all samples are shown in Table 4. A computerized search of the raw data was made to determine whether any parameter(s) showed a significant difference in any room, and it was found that in one instance only -- room 12, 1:00 p.m. sample, respirable colony-forming particles (CFP) -- was there a significant increase caused by reduced ventilation. When each room was examined, individually, for a similar effect, no statistical difference was found among rooms; hence, the effect was not a general one and may have been incidental to ventilation conditions within that particular room. Deleting the data collected from the auditorium did not reveal any new correlations of statistical significance.

Table 5 shows how the mean values of the number of CFP vary with sampling time and follow a repetitive daily pattern corresponding to classroom activity periods.

Table 6 lists mean values of CFP/m^3 found in a number of locations over a two-year period and is representative of a general level of bioburden at these sites. A comparison between Carondelet High School and Fairmoor under existing conditions indicates that the number of CFP/m^3 at Fairmoor was double that at Carondelet. In looking at classrooms only, we find twice as many CFP/m^3 at Fairmoor (269) than at Carondelet (134) under existing conditions. At Fairmoor, the number of CFP/m^3 increased from 269 to 360 when ventilation was decreased from existing to sealed conditions. A microbial burden in this range is not unusual, as supported by data taken from other buildings.

The number of airborne CFP in the auditorium-gymnasium varied more than in any other room tested at any site. This variation,

Table 4. Mean numbers of CFP/m^3 in two classrooms at Fairmoor Elementary School, excluding 8:00 a.m. sample.

Mode of ventilation	Total particles		Respirable particles		Non-Respirable particles	
	Mean	Stand. dev.*	Mean	Stand. dev.	Mean	Stand. dev.
Normal	269	166	104	68	165	110
Damper closed	253	188	116	74	141	126
Reduced	360	206	182	118	177	99

Note: Because of the large standard deviations, there are no significant differences between any of these means. However, in each case, a consistent increase is evident when the operating mode was changed from normal to reduced.

*standard deviation.

Table 5. Mean values of CFP/m^3 in classrooms at Fairmoor Elementary School, calculated as a function of time

Time	Normal	Damper Closed	Reduced
8:00 a.m.	13	32	19
10:00 a.m.	243	148	305
1:00 p.m.	256*	323	403*
3:00 p.m.	291	280	370

Note the difference between these two starred values. Since the vents were sealed, we could not have been observing an infiltration of air containing numerous CFP; the explanation could be that rather clean, infiltrating air was acting as a diluent under the normal condition in the rooms.

Table 6. Mean values (no. per cubic neter) of numbers of airborne colony-forming particles (CFP) at various sites.

Fairmoor Elementary School			
Ventilation:	Automatic	Dampers Closed	Sealed
	269	283	360
(Auditorium - Gymnasium had Peak Value of 1200)			
Carondelet High School (Class in session)			
Ventilation Rate (cfm/occupant)		Room 1	Room 2
13.5		160	107
2.5		115	75
Peralta Hospital (Eye Operatory)			40
Sports Arena			200
NBL Conference Room			180
NBL Men's Rest Room			132
Veterans' Administration Hospital (Martinez)			
Cast Room			333
Research House, Walnut Creek			
Sealed and Vacant			17
Blower On and Vacant			550
Long Beach Naval Hospital			
Cast Room			523
Patient Room			900
Proctology			62
Obstetrics			125
Pediatrics			183

from as low as $12/m^3$ to as high as $1200/m^3$, is not unexpected since occupant use of this area is highly variable. Although this factor prevented any analysis of the data in that room with respect to ventilation changes, it does indicate that higher levels of airborne CFP can be tolerated by humans without evident harm.

The following observations were made by NBL from the data amassed: It seems that humans live in air with "bioburdens" of from 20 CFP/m^3 to over 700 without apparent ill effects. There is no evidence that any retrofit situation examined caused an increase in airborne microflora above that present in other usual and common situations. Hence, the probability of infection from aerosols of human origin under normal and usual conditions (excluding the presence of "carriers" or "shedders", which is not really a part of the ventilation evaluation problem) seems vanishingly low. If that very small probability were increased ten-fold as a result of a ten-fold increase in bioburden then a very low probability of infection would still remain.

Data collection from the Oakland Gardens Elementary School is still in progress; data collected from the Fairmoor School and Carondelet High School[10] indicate that ventilation rates of 2.5 cfm/occupant are compatible with acceptable indoor air quality.

Energy Efficient Houses

The Maryland house was occupied by our field personnel during the month that this house was studied. The house had electric appliances and incorporated numerous construction features designed to reduce air leakage and energy consumption. Fig. 2 summarizes the air exchange rates, measured on a continuous basis. The average air exchange rate was approximately 0.15 ach, with shifts in weather conditions and routine door openings causing rates to vary from less than .05 to almost 0.3 ach. Levels of formaldehyde and radon in this house were frequently found to exceed existing health standards.

The MED-II minimum energy dwelling in southern California was occupied by a family at the time of monitoring by the EEB Mobile Laboratory. This house was equipped with gas-fired kitchen appliances, which are known to be sources of indoor pollution.[11] Air-exchange rates were found to average approximately 0.4 ach. Pollutants measured in this house and in other buildings tend to fall into three categories: those whose primary sources are indoors (e.g., CO_2 and aldehydes), those whose primary sources are outdoors (e.g., O_3 and SO_2), and those which have both indoor and outdoor sources (e.g., NO, NO_2, CO and particulates). Those belonging to the first group are generally present in higher concentration indoors than outdoors, and tend to show even higher levels as air-exchange rates are lowered. On the other hand, as buildings are tightened, occupants are shielded from pollutants in the second group, particularly from reactive substances such as O_3 and SO_2. Substances in the third group may exhibit higher indoor concentrations as air exchange rates are reduced, depending upon the relative indoor and outdoor source strengths.

Fig. 3 shows the frequency distribution of carbon dioxide concentrations at the MED-II house. Although indoor concentrations obviously exceed those outdoors, they do not approach the occupational standard of 5000 ppm. Fig. 4 shows indoor and outdoor ozone concentrations for the same period. This pollutant, a major component of photochemical smog in the Los Angeles area, is highly reactive and, as evidenced from the figure, indoor levels are significantly lower than outdoor levels. Fig. 5 shows the indoor and outdoor concentrations of nitrogen dioxide. Nitrogen oxides are produced from combustion processes, whether outdoors (power plants, automobile exhaust) or indoors (natural gas combustion). As can be seen from the figure, indoor

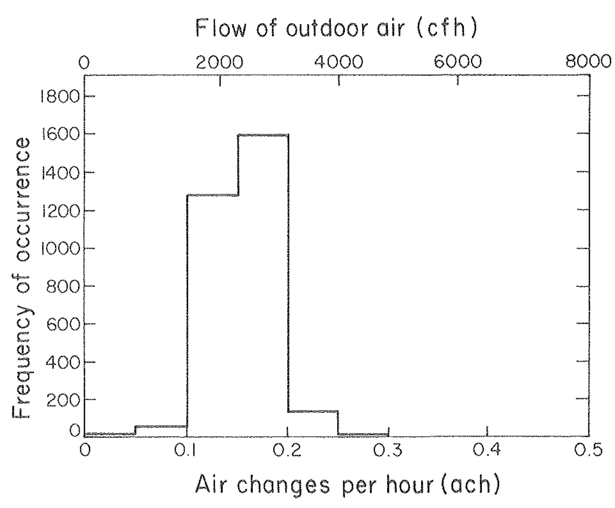

Fig. 2. Frequency distribution of air exchange rates at ERHM. (XBL 7910-4298)

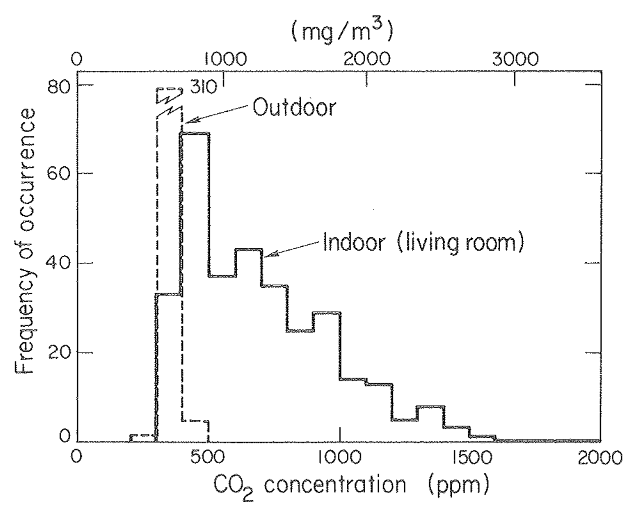

Fig. 3. Frequency distribution of CO_2 concentrations at MED-II house. (XBL 7910-4356)

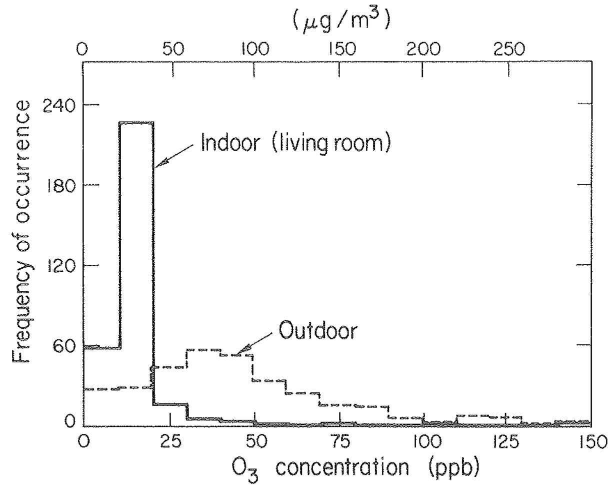

Fig. 4. Frequency distribution of O_3 concentrations at MED-II house. The graph represents data collected between 8:00 a.m. and midnight during occupancy. Indoor concentrations did not exceed 110 ppb. (XBL 7910-4359)

NO_2 levels are sometimes higher than those outdoors and these increases have been correlated with cooking activities. The proposed EPA standard for ambient air is 470 $\mu g/m^3$, which was occasionally exceeded in this house. Analysis of the particulate data from the MED-II house indicates that although the outdoor particulate concentrations usually exceed those indoors, again, cooking activities are capable of reversing this situation.

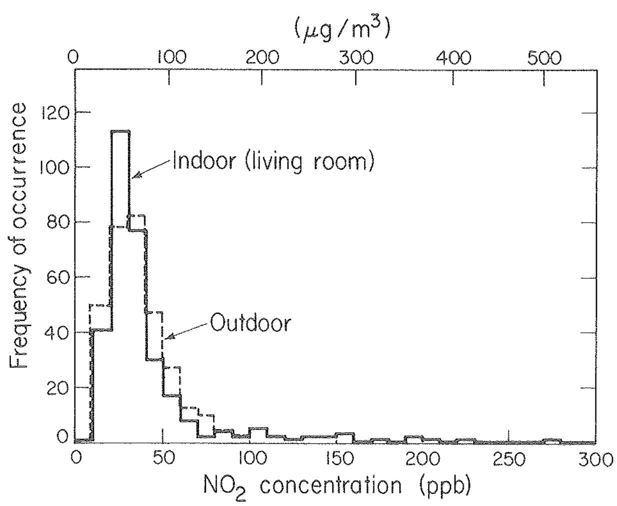

Fig. 5. Frequency distribution of NO_2 concentrations at MED-II house. The graph represents data collected between 8:00 a.m. and midnight during occupancy. (XBL 7910-4361)

Preliminary data collected on energy-efficient residences indicates that a minimum air-change rate of approximately 0.5 ach may be necessary to prevent the indoor concentrations of some pollutants from exceeding existing or recommended U.S. standards for ambient air and standards promulgated by other countries. Air-to-air heat exchangers are effective in maintaining good indoor air quality without sacrificing energy conservation goals. For confined indoor sources of pollutants, such as gas stoves, spot ventilation may be an appropriate solution. These alternatives are documented in more detail elsewhere in this report.

Additional Field Monitoring (Subcontractors)

As noted previously, in addition to Fairmoor School, TRC has performed measurements of odor perception, odor acceptability and odorant composition under variable ventilation conditions at the University of Connecticut Medical Center and at a San Francisco office building. The San Francisco office building data was taken during the last two weeks of September and has not yet been fully analyzed.

University of Connecticut Medical Center (TRC)

Odor and ventilation rates were measured at the University of Connecticut Medical Center (Hartford, Connecticut) during the month of May. Results of these measurements are presented in Table 7 for three areas of the hospital. As can be seen, only minor elevations in ED_{50} and odor intensity values (butanol scale) occurred when ventilation rates were reduced. In admissions and in the nurses' area, ventilation rates were reduced by a factor of more than two (to approximately 2.75 ach) which is still higher than the minimum recommendation set forth by Hill Burton or ASHRAE standards. Thus, it is not surprising that we see no significant increase in odor levels at "reduced" ventilation rates. Measurements of acceptability indicated that employees always found the odor level less acceptable than the visiting odor panelists. This finding was unexpected and contrary to usual assumptions. When ventilation was reduced, however, neither group noted a change in odor acceptability.

As with the Fairmoor School classrooms, odorant concentrations were too low to allow positive identification by gas chromatographic odorogram analysis. In general, the nurses' and patients' areas had more organic material in the air than the admissions area, with the nurses' area showing the most. In all areas, reducing the ventilation caused the amount of organic material to approximately double, a finding which correlates well with the fact that, in most cases, fresh air was decreased 50% in the reduced mode. Major compounds identified by GC/MS for the nurses' area were: ethanol, butene, methyl propane, acetone, isopropanol, 2-methyl-1, 3-butadiene, benzene, ethyl benzene, 1, 1, 1-trichloroethane, toluene and xylene.

Table 7. Summary of odor and ventilation data, University of Connecticut Hospital.

	Odor Dilution Ratio (ED_{50}) Normal	Reduced	Odor Intensity Butanol Scale (ppm) Normal	Reduced	Ventilation Rate (cfm) per person (ach) Normal	Reduced
Admissions						
AM	11.1	9.2	183	134		
PM	8.0	14.5	173	176		
Mean	9.5	11.8	177	155	164 (6ach)	75 (2.8ach)
Nurses' Area						
AM	6.4	5.2	148	141		
PM	8.1	6.3	156	174		
Mean	7.3	5.9	152	158	65 (6.5ach)	27 (2.7ach)
Patient Room						
AM	8.9	5.9	173	116		
PM	7.6	7.8	154	184		
Mean	8.2	6.9	162	150	101 (5.2ach)	79 (4.1ach)

East Coast Schools and Hospitals: One-day surveys

Thus far, one-day survey data on odor and ventilation rates have been analyzed for four schools and two hospitals on the East Coast. Table 8 summarizes the results of these surveys. The four schools sampled were found to be free of odor problems. Both the odor dilution ratios and odor intensity levels were low with one exception, Room 15 in the W. H. Grammar School, where the odor intensity level was much higher than would be expected from the odor dilution ratio. In general, the schools were found to be over-ventilated with ventilation rates in classrooms ranging from a high of 41.6 cfm per person to a low of 4.6 cfm per person, for an average of 23.5 cfm per person. This compares to the ASHRAE standard for classroom ventilation rates of 10 cfm per person minimum and 10 - 15 cfm/per person recommended.

The two hospitals sampled were also found to be over-ventilated except for the ward room in the Hartford Hospital. Again, there was no existing odor problem in either of these hospitals; ED_{50} values and odor intensity were low in all cases except for the outpatient lounge in Hartford Hospital.

Experimental Aerosol Studies (NBL)

The purpose of these experiments was to study the effects of particulate filters (0 to 80% efficiency) and varying fresh-to-recirculating air ratios on the removal rate of microbes in hospital spaces.

A 2000 ft^3 experimental chamber was built. The chamber was supplied with facilities for air recirculation, cleaning, and treatment (conditioning) as if it were to be used as a habitat, except that the intake of fresh air (%), recirculation rate, and filter efficiency could be easily varied. Samplers for airborne bacteria and for inert particles, and a spinning-disk aerosol generator, were placed in the room.

Using controlled conditions, a one-minute "burst" of aerosol containing a "tracer" bacterial species was dispersed into the chamber and then sampled at intervals for a period of sixty minutes. The number median diameter (NMD) of the aerosol was 5.5 μm.

The following variables that might influence the removal rate of the aerosol were examined: (a) filters of "zero", 20, 60, and 80% efficiency; (b) air exchange ratio of 6 and 12 air changes per hour (67% recirculated air), and (c) 33% or no fresh air intake (100% recirculation).

By comparing observed clearance rates during the first 1/2 hour to the removal rates that prevail when the space is ventilated with 100% fresh air, NBL concluded that it should be possible to reduce fresh-air intake in commercial buildings and, by using combinations of recirculating air, filters, air exchange rates, and recirculation percentages, provide air of essentially the same particulate cleanliness as found in 100% clean fresh air. These studies are described in detail in NBL's April 1979 report to LBL.[9]

Table 8. Odor and ventilation data, six East Coast schools and hospitals.

SITE	Odor Dilution Ratio (ED_{50})	Odor Intensity Butanol Scale/(ppm)	Room Volume (Ft^3)	Actual Occupancy	Air Changes Per Hour	Ventilation Rate cfm/Occupant
U.C. Dental School (3/20)						
Room L003	2.0	2.8/60	7455	22	5.5	31.2
Room BM031	5.2	2.4/47	9086	55	15.1	41.6
Blue Auditorium	5.2	3.3/86	53360	110	3.0	25.1
S.D. Junior HS (3/21)						
Room 102	8.1	2.3/52	5832	16	2.8	17
Room 109	7.5	3.0/77	5832	22	5.9	26
Gym	8.5	2.8/70	119784	20	1.3	128.
E.W. Grammar School (3/22)						
Room 3	4.4	3.0/83	8125	22	2.6	16.
Room 10	3.6	1.5/32	9315	24	0.7	4.6
Art Room	7.9	2.9	14702	20	1.2	14.3
U.C. Medical Clinic (3/23)						
Patient Room - 2116	10.8	3.0/77	2330	2	6.7	131.0
Nurse's Area - 2nd Fl.	5.9	3.4/107	4770	8	9.4	93.7
Admissions	9.0	3.9/139	16120	10	7.2	193.0
W.H. Grammar School (6/7)						
Room 15	13.0	4.8/264	10008	21	2.5	10.9
Room 16	8.3	3.2/99	10100	20	3.7	31.1
Art Room	15.6	3.2/99	16165	16	2.0	33.7
Hartford Hospital (7/23)						
Outpatient Lounge	46.9	5.3/460	4414	15	6.3	31.0
Ward 522	15.6	3.6/146	2667	6	0.2	1.5
Cafeteria	6.8	3.9/173	95737	200	5.9	47.1
Outside Air Samples						
3/20	30.1*	2.8/60				
3/21	3.4	1.9/40				
3/22	5.2	2.4/52				
3/23	7.9	2.6/58				

* Sample probably contaminated by Chemistry Lab exhaust.

To reduce energy use in conditioning air without creating a severe increase in the bioburden, NBL suggested the following remedies:

1. Use medium to low efficiency filters.

2. Reduce total volumetric flow rates.

3. Use particulate filters with efficiency approximating "0" to 80% efficiency (ASHRAE Test) in air-recirculating systems.

PLANNED ACTIVITIES FOR 1980

The following sites will be included in the field monitoring studies of indoor air quality during FY 1980:

- Oakland Gardens Elementary School, Bayside, New York

- Fridley Jr. High School, Minneapolis, Minnesota

- Two energy efficient research houses, Northfield, Minnesota

- Underground research house, Minneapolis, Minnesota.

TRC will complete its analysis of field data from the San Francisco office building and the six other odor-monitoring sites in FY 1980. One more intensive field-monitoring study will be conducted at Oakland Gardens Elementary School in New York City. When all the data have been analyzed, TRC in consultation with John Pierce Foundation (see Subcontracts section) will recommend ventilation rates for odor control in schools and hospitals.

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MECHANICAL VENTILATION SYSTEMS USING AIR-TO-AIR HEAT EXCHANGERS

G. D. Roseme

INTRODUCTION

Many homes in the United States and in Europe have conserved energy by reducing infiltration. When a house is thus "tightened", however, various indoor air contaminants are sealed in and tend to build up, e.g., odors from human activity, chemical contaminants from cooking and other combustion activity in the household, moisture, formaldehyde emitted from building materials and furnishings, and radon gas from soil, water and building materials. With the broad aim of assuring acceptable indoor air quality in "airtight" houses without sacrificing the energy efficiency of the house, the Ventilation Program initiated a research project in October, 1978 designed to investigate the use of mechanical ventilation systems incorporating air-to-air heat exchangers.

A heat exchanger or heat recovery device installed directly in the mechanical ventilation system brings the incoming and exhaust air streams into close proximity so that heat can be exchanged between the two air streams (see Figs. 1 and 2). When such devices are installed in an

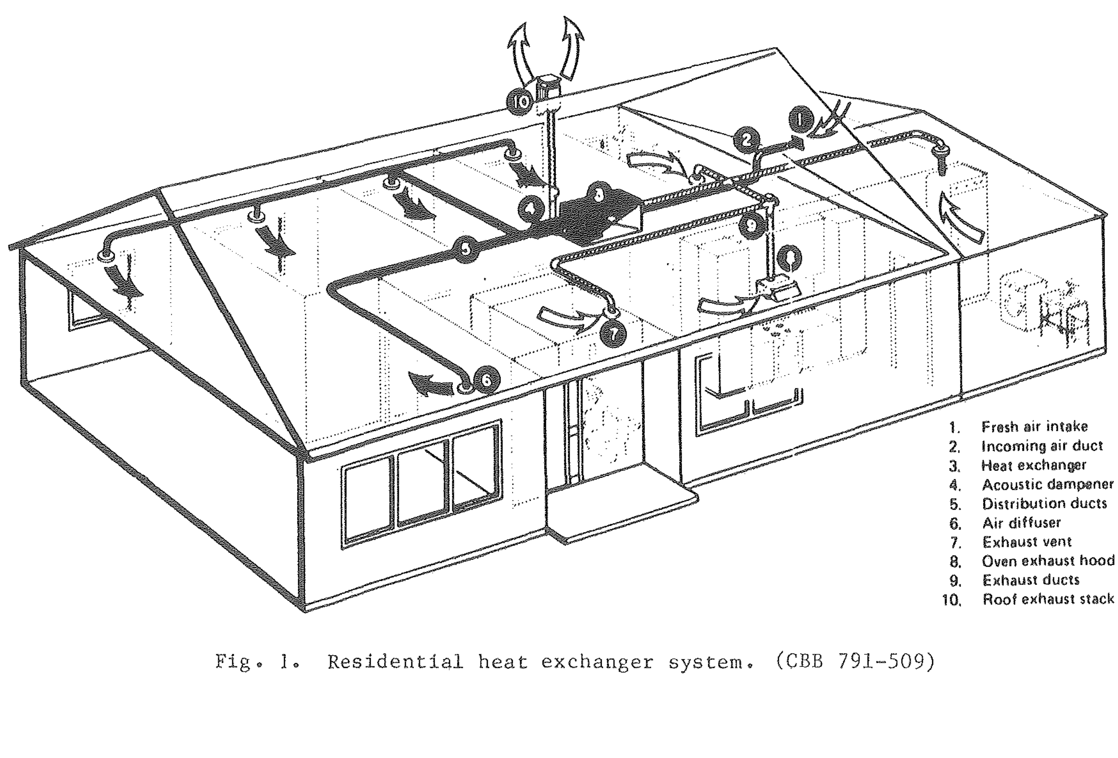

Fig. 1. Residential heat exchanger system. (CBB 791-509)

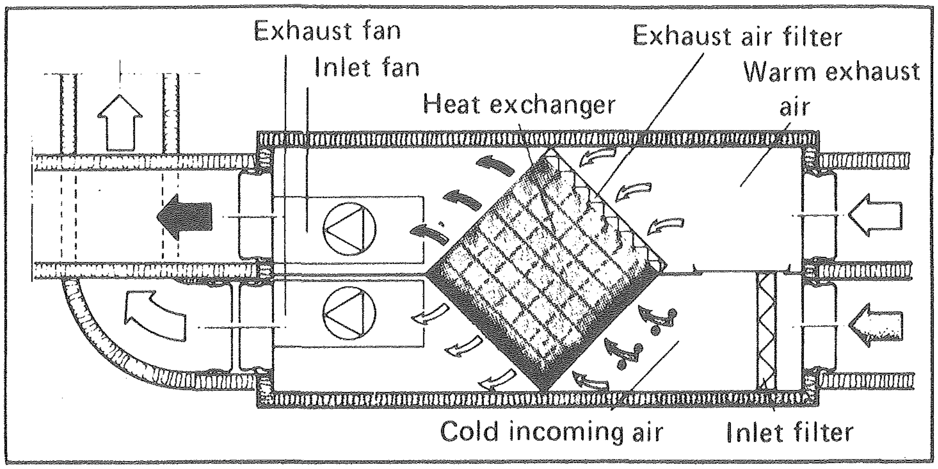

Fig. 2. Principle of operation of heat exchanger. (CBB 791-507)

energy-efficient house, the concentration of indoor-generated contaminants are reduced without compromising energy-conservation.

The Ventilation Program Staff developed four study areas for this project:

1) Analysis and experimental evaluation of air-to-air heat exchangers;

2) Testing of a mechanical ventilation system utilizing an air-to-air heat exchanger in the EEB Walnut Creek house;

3) A cost-benefit analysis of these systems operating in different climate zones of the United States.

4) Installation and testing of a number of systems in occupied homes.

ACCOMPLISHMENTS DURING 1979

A heat exchanger test facility has been constructed at the Richmond Field Station of the University of California at Berkeley (see Fig. 3). This facility is capable of measuring the effectiveness, pressure drop, and cross-contamination of residential-sized air-to-air heat exchangers, and can simulate outdoor conditions from $0^{o}F$ up to $100^{o}F$ with high relative

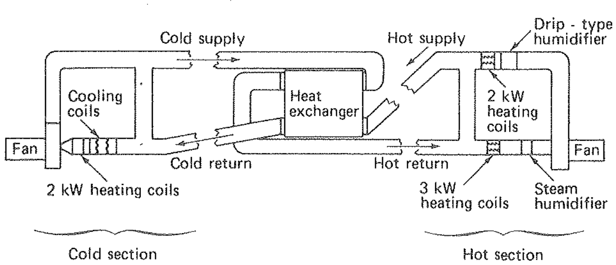

Fig. 3. Heat exchanger test facility. (XBL 7910-4480)

humidity levels. Actual testing of air-to-air heat exchangers will begin early in FY 1980.

During 1979, heat exchanger systems were installed in two unoccupied research houses. One house, belonging to the National Association of Home Builders and located in Mt. Airy, Maryland, was already determined by our Energy Efficient Buildings (EEB) Mobile Laboratory to have high moisture, radon and formaldehyde levels. Under a subcontract to LBL, the National Association of Home Builders Research Foundation Inc. installed two mechanical ventilation systems and are currently measuring indoor air-quality parameters in the Mt. Airy house as a function of ventilation rate. These parameters include indoor and outdoor dry bulb temperature, relative humidity, formaldehyde concentration and radon concentration.

The second house is an unoccupied house in Walnut Creek, Ca. where we are studying methods of controlling combustion-generated pollutants from gas stoves. We have installed a mechanical ventilation system with an air-to-air heat exchanger and are investigating various ventilation strategies, including spot ventilation to improve indoor air quality in the house.

PLANNED ACTIVITIES FOR 1980

Under subcontract to Lawrence Berkeley Laboratory, the Department of Mechanical Engineering of University of California Berkeley, since October 1978, has aided in the design of the Richmond Field Station Heat Exchanger test facility, and has provided us with an analysis of both permeable and non-permeable wall exchangers operating in dry (noncondensing) conditions. Beginning in October, 1979, they will be developing calculation methods for determining heat-exchanger effectiveness as a function of flow rate, for both porous and non-porous wall materials and for exchangers operating with and without condensation and with freezing on the heat-transfer surface. Using these analyses, they will compare their theoretical predictions with experimental performance as measured at our Richmond Field Station test facility and with manufacturers' specifications.

During the winter of FY 1980, the EEB Mobile Laboratory will measure indoor air-pollutant concentrations in two energy-efficient homes in Northfield, Minnesota. Both of these homes are quite airtight (measured natural infiltration rates of less than 0.2 air changes/hour under windy conditions). One of these houses has a mechanical ventilation system that uses a U.S. manufactured heat-pipe heat exchanger to recover the waste heat from the exhausted air. We are currently negotiating to install a ventilation system with an air-to-air heat exchanger in the second house before the mobile lab arrives.

Contract negotiations are underway with the New York State Energy Research and Development Authority, Rochester Gas and Electric Company, and The Rochester Institute of Technology for a collaborative program to examine the airtightness of approximately 60 homes in the Rochester, New York area. The airtightness of these homes will be measured with a blower door unit supplied by LBL. A number of indoor air-quality parameters will be measured in selected homes. If indoor air-quality problems are found, mechanical ventilation systems with air-to-air heat exchangers will be installed and energy efficiency, operating problems, and indoor air pollution in these houses will be monitored over a period of two years.

SUBCONTRACT ACTIVITIES

I. Turiel

INTRODUCTION

In addition to activities conducted by the Naval Biosciences Laboratory (NBL) and The Research Corporation of New England (TRC), discussed under "Field Monitoring", and work being performed by the University of Minnesota, described under the Hospitals Program, the Ventilation Program has been directing two other major subcontracts:

- o Assessment of ventilation requirements for odor control (John Pierce Foundation, New Haven, CT)
- o Development of automatic variable ventilation control systems (Honeywell, Inc., Minneapolis, MN)

ACCOMPLISHMENTS DURING 1979

Odor Control (John Pierce Foundation)

In order to carry out experiments on ventilation requirements for odor control, it is necessary to have a test room where the environment can be regulated at will. The John Pierce Foundation completed construction of a 1,200 ft^3 test chamber in June 1979 at their laboratory in New Haven, Connecticut. The environment in the all-aluminum chamber can be controlled for temperature, humidity and ventilation rate. The objectives of these laboratory experiments are to:

1. Determine how odor magnitude, odor acceptability, and odor detectability vary with the rate and type of contaminant generation, rate of ventilation, temperature and humidity.
2. Compare air acceptability as perceived by occupants in an experimental chamber with that perceived by visitors to the chamber.
3. Assess the efficiency of solid granular media for controlling odors under conditions of reduced ventilation.

In all experiments planned, the primary independent variables are:

a. type of contaminant

b. rate of contaminant generation

c. rate of ventilation

d. presence/absence and type of filter media and

e. environmental conditions

One experiment on body odor serves as a typical example: Variables c, d, and e above are predetermined for each experiment. Occupants enter to serve as odor generators. Persons are stationed at a sniffing port outside the chamber (where air from the chamber is exhausted) to act as odor judges. At periodic intervals, judges record odor detectability, intensity, and acceptability. (The same type of olfactometers are used as in the TRC odors field work described in the Field Monitoring section.)

Figure 1 presents results on body odor experiments at ventilation rates of 3.3, 5.0 and 10 cfm per occupant, three temperature settings, and two humidity conditions. Although the air space per person (100 ft^3) is quite low compared with typical occupied spaces in buildings, the air was found to be generally acceptable. As indicated on the figure, an odor-intensity reading of 4 or less means that 80% of the judges found the air odor acceptable. When the temperature is kept below 25.5°C and the relative humidity below 70%, a ventilation rate of 5 cfm/person appears adequate to maintain acceptable odor level even under such crowded occupancy conditions. This finding is in contrast with earlier results reported by Yaglou, et al.[1]

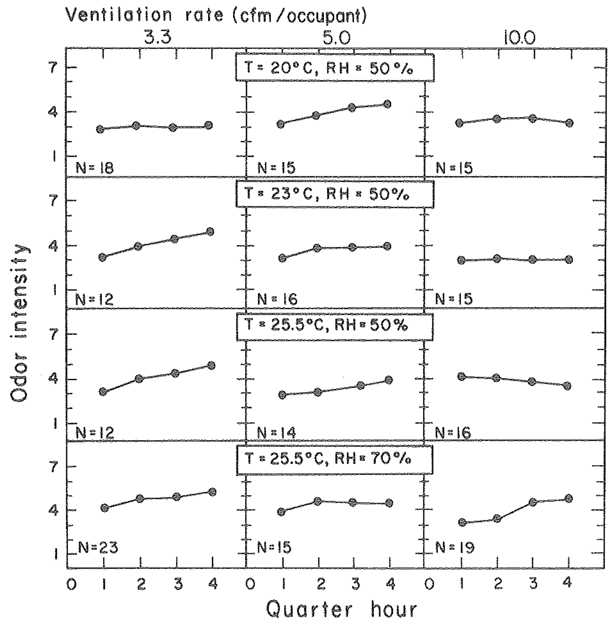

Fig. 1. Odor intensity as a function of temperature and relative humidity. (XBL 801-72)

which specified that 25 cfm/person was required to produce an acceptable odor level under the above occupancy conditions. These results from the John Pierce Foundation are only preliminary, however.

Continuing experiments in this area will test other odorous substances. From these findings, it will be possible to construct "families" of psychophysical functions relating perceived odor magnitude in steady-state or quasi steady-state conditions to levels of concentration of an odorous contaminant, number of occupants, rate of ventilation, etc.

Corollary work undertaken by the John Pierce Foundation -- a review of existing regulations for odor control in buildings and their underlying data base -- together with a discussion of odor-measurement techniques and air-treatment systems for odor control in buildings, has been completed and published as an LBL report, Ventilation and Odor Control: Prospects for Energy Efficiency.[2]

PLANNED ACTIVITIES FOR 1980

In FY 1980, the John Pierce Foundation will continue experiments on ventilation requirements for control of body and tobacco odors with the objective of establishing ventilation rate recommendations under various conditions of occupancy and thermal environment. The ability of several solid materials to adsorb odors under various conditions will also be assessed.

Variable Ventilation Control Based on Air Quality Detection

Honeywell, Inc. was subcontracted to develop and demonstrate an automatic variable ventilation control system based on air-quality detection for various institutional and commercial building types. The air-quality detector was to be sensitive to changes in the number of occupants and activity loads. Field work in schools and office buildings has indicated that CO_2 concentration and occupancy are closely related.[3]

At the end of FY 1979, Honeywell installed a variable ventilation control system in the music wing of Fridley Junior High School, located in the greater Minneapolis area.

Occupancy/activity levels are sensed by fluctuations in CO_2 concentration, and the detector output signal controls the outside air damper. The HVAC system was modified to allow measurement of air velocities, temperature, and relative humidity in several return and supply air ducts, and also to measure the energy consumed by the hot water reheat coils.

For space heating, the HVAC system can be operated in three modes. The first mode, the "BEFORE" mode, supplies air at 55°F to the reheat coils which reheat the air to maintain space conditions; the second mode is an ENERGY EFFICIENT mode where the air temperature supplied to the reheat coils is reset so that it is no colder than required to keep the warmest reheat zone from over-heating; the third mode, also an ENERGY EFFICIENT mode, is the automatic variable ventilation mode where the amount of outdoor air introduced will be the minimum amount required to prevent the CO_2 level in the occupied zones from rising above the control level for CO_2, or the amount of outdoor air required to prevent overheating while the HVAC system is operating on the "free" outside air cooling cycle. When operating in this last mode, ventilation air is introduced through an outside air-damper section (Fig. 2) and an air measurement device. This damper section, as well as the thermal outside air damper and the exhaust air damper, are of a "low leakage" design to minimize the introduction of unwanted outside air. Two small exhaust fans in the HVAC system were disabled and sealed off so that the only exhaust capability of the tested area will be that of the central return-exhaust fans.

PLANNED ACTIVITIES FOR 1980

During 1980, the control system will be tested for its reliability in maintaining adequate indoor air quality with maximum energy conservation. Energy consumption data from these three modes of operation will be normalized for weather variance and compared with each other to evaluate the benefits derived from ventilation control systems based on CO_2 detection.

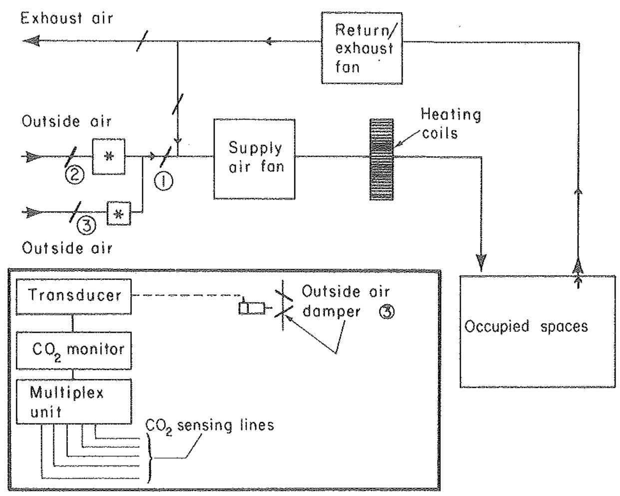

Fig. 2. Control modifications to heating, ventilation and air conditioning system at Fridley Junior High School. (XBL 801-73)

A similar evaluation will be conducted for the "peak" cooling period of operation. The "peak" cooling period occurs during those occupied times when the outdoor air has a higher enthalpy (more heat) than the return air. The control modes will again be "BEFORE," "ENERGY EFFICIENT" and an ENERGY EFFICIENT mode where the amount of outside air is minimal and controlled to maintain interior air quality as measured by CO_2 content in the occupied spaces. The occupants of the music wing will be asked to complete a questionnaire daily, as a means of assessing their perception of the indoor air quality under various ventilation conditions.

As indicated under "Field Monitoring," the LBL EEB Mobile Lab will be brought to Fridley Junior High School during the month of February to determine the effectiveness of the ventilation control system in maintaining acceptable indoor air-quality. In addition, Honeywell will proceed with the following tasks:

- Determine the cost-effectiveness of variable ventilation control systems and estimate expected national energy savings.
- Assess commercialization potential of variable ventilation control systems.

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2. W.S. Cain, L.G. Berglund, R.A. Duffee and A. Turk, Ventilation and Odor Control: Prospects for Energy Efficiency, Lawrence Berkeley Laboratory Report, LBL-9635 (November 1979).

3. I. Turiel, C.D. Hollowell and B.E. Thurston, Variable Ventilation Control Systems: Saving Energy and Maintaining Indoor Air Quality, Lawrence Berkeley Laboratory Report, LBL-9380 (June 1979).

VENTILATION - INDOOR AIR QUALITY DATA BASE

R. Langenborg

INTRODUCTION

The Ventilation Indoor Air Quality (VIAQ) data base is a computerized information service developed by the Ventilation Program, a major component of the Lawrence Berkeley Laboratory Energy Efficient Buildings Program. This program is part of a coordinated effort to respond to the need for national energy conservation, while concurrently ensuring satisfactory indoor air quality for building occupants. To this end, Lawrence Berkeley Laboratory (LBL) is conducting research and development on existing and proposed ventilation requirements and mechanical ventilation systems. The program will produce recommendations for energy-efficient ventilation standards and designs for residential, institutional and commercial buildings.

Various segments of the professional community have expressed a growing interest in energy conservation as applied to the built environment. A partial listing of those concerned include: architects, building contractors, design engineers, legislators/administrators, mechanical engineers, professors/educators, public health officials, researchers and scientists.

In an effort to meet the needs of these specific groups, as well as the commercial sector and the general public, LBL is in the process of establishing an information clearinghouse for ventilation indoor air quality research (VIAQ). The basic objective of the VIAQ Data Base project is to consolidate existing information with current research developments and to make this information directly accessible to user groups throughout the country.

Access to the data base will occur via an interactive session between the user and VIAQ. Communication (data links) may be established through commercial telephone lines, or high-speed computer networks. User equipment requirements are minimal--a telephone, a computer terminal, and an acoustic coupler. Once the connection has been achieved, the typical user will be interactively guided through selected resource modules.

When the VIAQ data base is fully operational, it will include information on the following items:

1. Air Quality Resources
2. Bibliography
3. News
4. Seminars, Workshops and Conferences
5. Who's Who
6. Ventilation-Research and Development Projects
7. Ventilation-Business and Finance
8. Ventilation-Standards and Guidelines
9. Models
10. Analysis Programs
11. User Alert Service
12. Hard-Copy Output
13. Utility Routines
14. Help

In the prototype version, LBL is preparing to bring on-line the following modules:

Module 1: A current listing of data base resources to inform users of existing search facilties.

Module 2: The bibliographic resource including bibliographic references, abstracts, and thesaurus, covers subject areas such as indoor air quality, airborne contaminant control, hospital ventilation and energy conservation, infiltration, windows and lighting, and radon. Each bibliographic entry includes source reference information including: author name and affiliation, publication type, language of the original article, abstract and keywords. Abstracts are maintained on-line to aid the user in determining whether he/she wishes to obtain the complete document. Original author-prepared abstracts are utilized wherever possible; however, LBL has supported abstracting activities to ensure adequate subject coverage. The indexing process, a vital part of bibliographic control, employs a consistent vocabulary (thesaurus) of keywords to describe the content of each document. The VIAQ on-line thesaurus conceptually structures keywords into broad, narrow and/or related terms, which will be used in the retrieval process.

Module 3: Current information and announcements, including data base updates, are obtainable in News.

Module 5: Who's Who is a listing of names, affiliations, and interest areas for researchers and officials working in building ventilation/indoor air-quality activities. The module may be used to generate specialized mailing lists or to link with the bibliographic module to immediately provide addresses and telephone numbers for authors of interest.

Module 12: When a session is terminated, final results may be printed on a hard copy peripheral to the user, or hard copy may be requested from LBL.

Module 14: Should the user have difficulty during a session, he/she may summon "help" at virtually any phase in the dialog, and instructions will be issued suggesting an appropriate remedy.

WHO'S WHO IN VENTILATION DATA BASE RESOURCE

Data collection is currently underway for module 5, the "Who's Who" resource module of VIAQ. This listing will facilitate contact among individuals by providing the user with pertinent information regarding other researchers who are involved in the ventilation/indoor air quality field. Searchable fields for this resource are name, affiliation and area(s) of interest.

Typical interest areas are as follows:

1. Airborne Microbes
2. Administration/Management
3. Building Envelope
4. Computer Analysis
5. Energy Conservation
6. Energy Efficient Buildings
7. Epidemiology
8. Field Studies
9. Formaldehyde
10. Heat Exchangers
11. Indoor Air Quality
12. Infiltration
13. Instruments/Instrumentation
14. Mathematical Models

15. Odors

16. Organics

17. Radon

18. Standards/Guidelines

ACCOMPLISHMENTS DURING 1979

Information analysis activities in FY 1979 centered on the following bibliographics:

In the area of air quality and energy conservation in hospitals, emphasis is placed on the patient environment, with respect to heating, ventilating, and air conditioning parameters. Topics include 1) general air hygiene, h^spital-acquired infections, 2) characterization of gaseous chemical contaminants detected in the hospitals, 3) hospital-specific contaminant control procedures, and 4) variables affecting patient comfort, such as temperature, humidity and odor level.

The survey of literature by the Infiltration Group includes studies of single-family structures as well as high- and low-rise commercial buildings. Measurement techniques used include tracer gas, pressurization, and wind tunnel investigations. Influences due to wind, temperature, humidity, and terrain are also covered.

Area	Source	Processing
Organic Chemistry*	LBL	data entry
Radon	LBL	validation, data entry
Odors	John B. Pierce Foundation	data entry
Contamination Control	LBL	validation
Hospitals	University of Minnesota	validation
Infiltration	LBL	coordination between infiltration and VIAQ group
Windows and Lighting	LBL	Coordination between Windows and Lighting Group and VIAQ.

The radon literature survey contains studies relating to the physical properties of radon and its daughters, instrumentation for their measurement, health effects, air-concentration surveys, and regulatory measures.

Literature surveyed by the John Pierce Foundation is an extension of the LBL contamination control survey. It encompasses existing and proposed ventilation requirements for odor control in buildings; odor measurement techniques, both analytical and subjective; and air treatment systems for odor control in institutional and commercial buildings.

In the area of contamination control, the literature survey is restricted to contaminant control theory and application in residential, commercial and public buildings. Areas of emphasis are toxic gas control, general odor control, and non-viable particulate control.

The Windows and Lighting Group is gathering bibliographic citations, patents, and standards on energy conservation as it relates to windows, and lighting.

A single hierarchical thesaurus of approximately 2,000 main terms has been established for keywording and searching the above bibliographics. The thesaurus contains synonyms and scope notes, and supports the standard binary relations between main terms (broader term, narrower term, related term). Data entry formats for technical bibliographic material (books, serials, analytics, "other") were established and underwent testing. A table-driven data entry program (UNIX software) was developed to accept these formats as record definitions, producing an interactive program that prompts the key operator for the appropriate information, validates when possible, and formats the output according to the requirements of a specific data-base management system.

The viability of modular design was demonstrated by bringing up various portions of the data safe on a PDP 11/70, utilizing UNIX and the Ingres data management system. By mid-July 1979, it became clear that VIAQ required a more production-oriented computer system, and the application was moved to an IBM 3033 housed at Stanford University. Existing data structures (primarily bibliographic records) were redesigned and programmed as file definitions in SPIRES, the general purpose data management system running on the IBM 3033.

PLANNED ACTIVITIES FOR 1980

The move to SPIRES delayed opening of the prototype data safe beyond FY 1979. It is currently scheduled for late January, 1980 and includes modules 1, 2, 3, 5, 12 and 14. Hard copy documentation of VIAQ modules will be generated in the 2nd and 4th quarters of FY 1980.

Tasks for FY 1980 are as follows:

Task 1: Continue to add program modules 3, 4, 6, 7, 8, 9, 10 and 11 to prototype version.

Task 2: Expand the data base to include information consolidation and dissemination tasks of other components of the EEB Program, e.g., Windows and Lighting Group, Infiltration. Generalized data storage structures have been established, and custom-user interface software will be provided to specific EEB user groups.

The full text and reduced data of EEB publications (e.g., "Windows") will be entered into the data base, allowing convenient editing, searching, and recall. High-quality hard-copy output of reports will be quickly available for widespread circulation.

Task 3: Begin software development to automatically monitor public use of the data base. Heavy-demand modules will be improved in terms of execution efficiency and user sophistication, while lower-demand modules may be reduced or eliminated.

Task 4: Coordinate efforts with related data base elsewhere. Export Ventilation Data Base to IEA Data Management Center.

In its final form, VIAQ will offer a leading-edge information service specializing in energy conservation and air quality in the built environment. In addition to the core subject matter, distinguishing features include wide public access, thoroughly indexed information, and direct user-to-data interface in a friendly computer environment.

DOE-2 COMPUTER PROGRAM FOR BUILDING ENERGY ANALYSIS

W. F. Buhl, R. B. Curtis, S. D. Gates, J. J. Hirsch, S. P. Jaeger, M. Lokmanhekim, A. H. Rosenfeld, J. V. Rudy, and F. C. Winkelmann

INTRODUCTION

For the past three years, LBL has been developing a comprehensive computer program for predicting energy use in buildings. Collaborating in this effort are LBL and Los Alamos Scientific Laboratory (LASL). LBL performs the role of lead laboratory. This program was formerly called Cal-ERDA and DOE-1.

The DOE-2 computer program is a tool that architects, engineers, and others can use to design new energy-efficient buildings and to analyze existing buildings for cost-effective energy-saving modifications.

The program has four main sub-programs:

1. LOADS--Computes hourly heating and cooling loads for each space in the building. The program differentiates loads due to infiltration, heat conduction, solar gain through windows, and internal gains generated by people, lights, appliances, and other equipment.
2. SYSTEMS--Simulates the operation of the HVAC distribution systems that heat and cool each space in the building and (in large buildings) distribute fresh conditioned air.
3. PLANT--Simulates the operation of the building's primary heating, cooling, and electrical plant, and calculates the hourly, monthly, and yearly energy requirements for the building.
4. ECONOMICS--Calculates the life-cycle cost of the building's mechanical system and energy-related features, including capital costs as well as maintenance,

operating and energy costs. This subprogram also performs a cost-benefit analysis; i.e., the user can input different design options which will be ranked on the basis of cost and/or energy use.

DOE-2 differs from its predecessor programs in two major respects:

1. It executes faster in the computer than other programs with similar purposes, and it is approximately five times cheaper to run. These features permit more alternative design options to be considered by the user as a basis for determining those most acceptable from a cost and energy-consumption point of view.

2. Where earlier programs read data cards filled with numbers punched in fixed format from forms filled in by the user, DOE-2 reads a "Building Description Language" (BDL), designed to increase speed, flexibility, and reliability of input. Special commands and keywords permit the user to specify building properties and parameters such as geometry, construction materials, schedules, HVAC systems, fuel costs, etc. Environmental data are provided via standard meteorological tapes of hourly weather conditions.

The overall logic and energy-flow diagram for primary HVAC systems of commercial buildings under DOE-2.1 are given in Fig. 1 and Fig. 2, respectively.

ACCOMPLISHMENTS DURING 1979

During 1979, two updates, DOE-2 and DOE-2.0A, were completed. Work is substantially underway on DOE-2.1, an expanded program selected by the Department of Energy as the benchmark for certifying compliance with the Building Energy Performance Standards (BEPS) to go into effect in 1980. This version of the program will include residential and packaged system simulation routines and will give the user the choice of (1) ASHRAE Weighting Factors and (2) Customized Weighting Factors as a basis for calculating heating and cooling loads for a given building.

Documentation was completed for the DOE-1, DOE-2, and DOE-2.0A programs. A new site manual for "Using DOE-2 at Lawrence Berkeley Laboratory" was completed by a sub-contractor (Jewson Enterprises).

DOE-2 is currently running at 47 sites, including: five national laboratories; ten universities; eight computer service bureaus; seven foreign sites; and two state energy commissions. These users, as well as others knowledgeable in building energy analysis, have been surveyed for advice on future developments of DOE-2. The DOE-2 User Coordination Office at LBL responded to nearly 400 telephone inquiries and/or requests for assistance in running DOE-1 and DOE-2.

The three-year verification project, assigned to LASL in 1978 by the Department of Energy, involves: (1) laboratory measurements of HVAC system components and comparison with DOE-2 simulations; (2) comparison of DOE-2 results

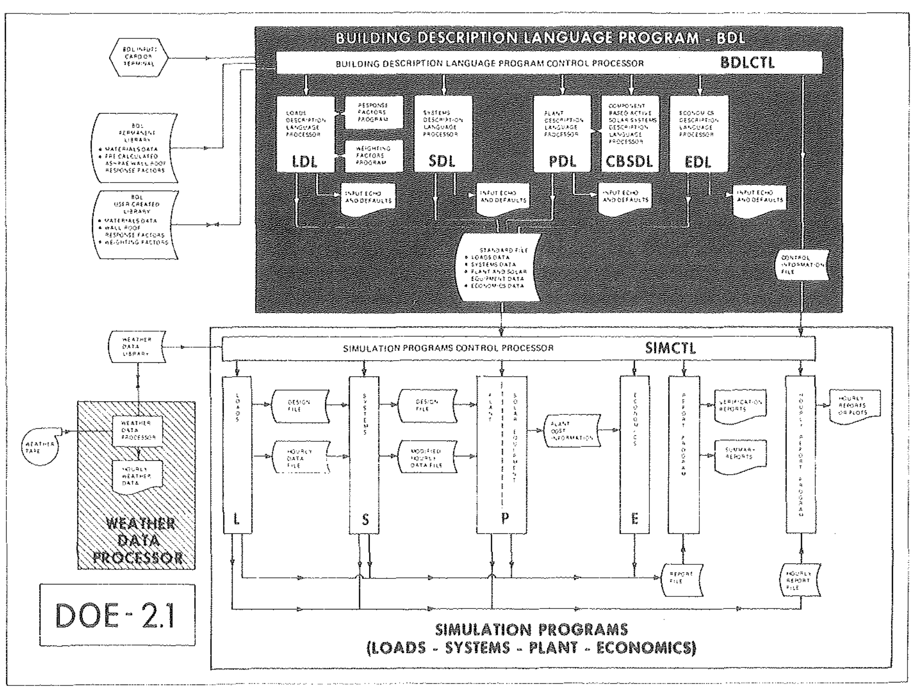

Fig. 1. DOE-2.1 simulation program for predicting energy use: overall logic. (XBL 7910-4353A)

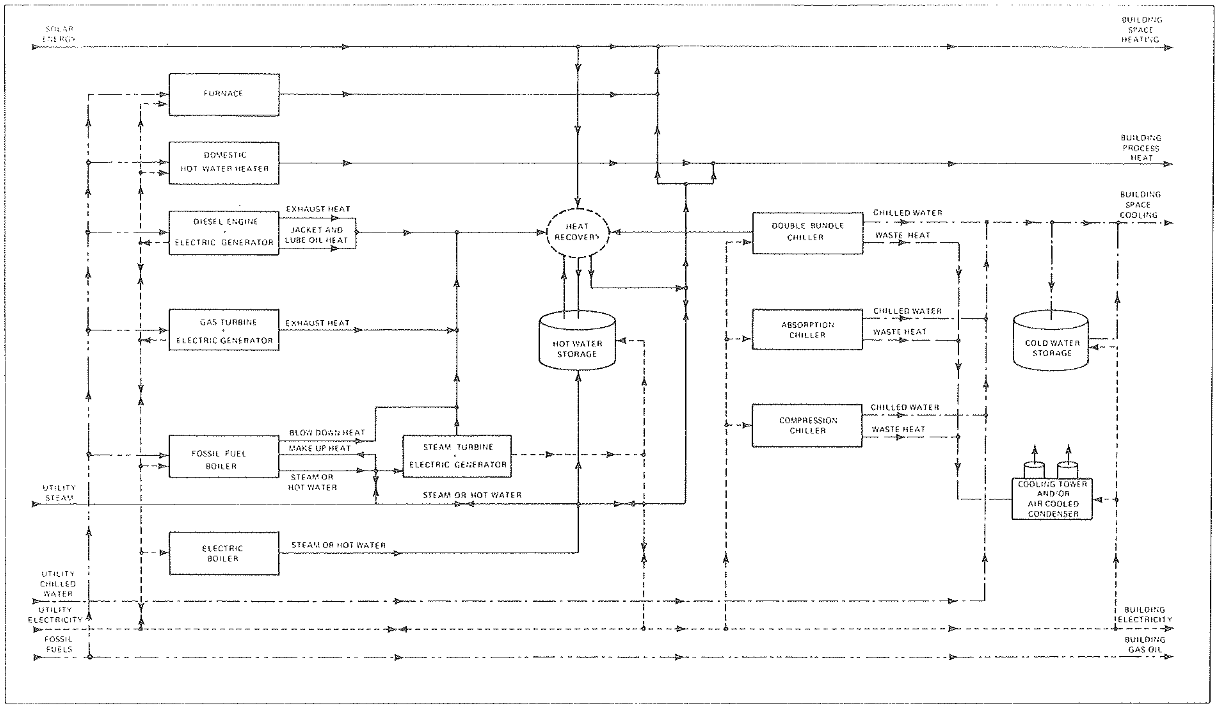

Fig. 2. Plant energy flow diagram for primary HVAC systems in commercial buildings. (XBL 7910-4354A)

with standard manual calculations; and (3) comparison of DOE-2 results with the actual energy consumption of six different commercial buildings.

In 1979, International Energy Agency (IEA) activities continued to perform: (1) energy use analysis of the Avonbank building, located in Bristol, England; (2) parametric studies on the energy use of the Avonbank building; and (3) comparisons of the energy use of the Avonbank building calculated by using different types of ASHRAE and Custom Weighting factors. The results of Task 1 were presented at the meeting of the International Energy Agency Executive Committee on Buildings and Community Systems in Copenhagen, Denmark (May, 1979). The results of Tasks 2 and 3 were presented at the meeting of the International Energy Agency Executive Committee on Buildings and Community Systems in Zurich, Switzerland (December, 1979).

Sample Energy Conservation Study with DOE-2

Significant energy and financial savings can be achieved by using DOE-2 for studying HVAC systems. Fig. 3 shows the results of 7 of the 10 different SYSTEMS and PLANT runs of a 31-story office building from the DOE-2 Sample Run Book 1. (Three of the runs are not shown because the buildings were simulated with unconventional primary HVAC systems.) Each run employed the same hourly LOADS file which was generated using Chicago TRY weather data. Results of other studies have been also incorporated in Fig. 3 in order to aid comparison.

The building typified 1974 construction, which did not quite conform to ASHRAE Standard 90-75. Details on Figure 3

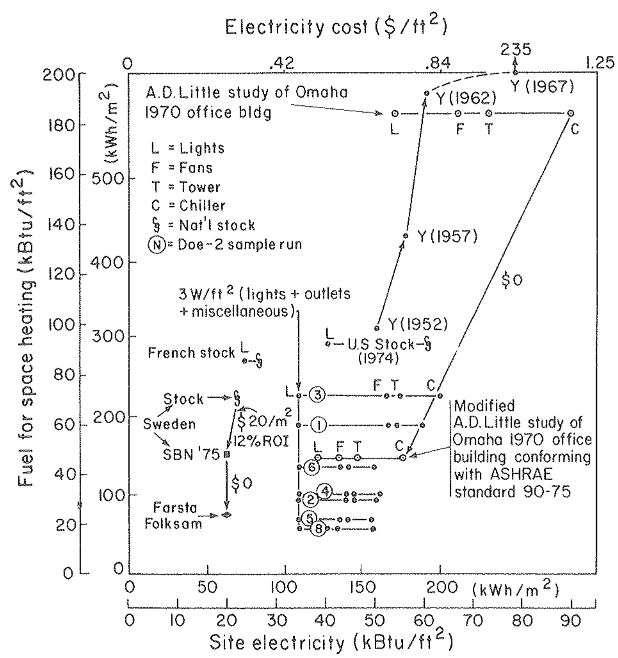

Fig. 3. Energy use in office buildings: fuel for space heating vs. site electricity (i.e., 1 kWh_e counted as 3600 kJ = 3414 Btu).[3] (XBL 793-891)

Each combination of a primary and secondary HVAC system is designated by a horizontal bar labeled by the run (system) number. The height of the bar indicates the amount of fuel consumed for space heating. Electricity consumed by the lights, outlets and miscellaneous building-wide operations is identical for all runs, and indicated by the dot on the bar labeled L. Electricity used by the fans, cooling tower and chiller is indicated by the dots labeled F, T and C, respectively; point C also indicates the cumulative total electrical consumption of the building.

The line at the top labeled "A.D. Little Study of Omaha 1970 Office Building"[2] corresponds to the calculated energy use of a 1970-style office building, built and operated energy-intensively. Energy use of the building was then recalculated to conform with ASHRAE Standard 90-75 and replotted. The line labeled "$0" connects the results of the two calculations and indicates that redesign led to no increase in first cost, despite reductions in site electricity use from 90 to 55 KBtu per ft^2 and in fuel use for space heating from 184 to 46 KBtu per ft^2.

The four Y's indicate energy used in large New York City office buildings constructed during 5-year intervals between 1950 and 1970. These buildings are equipped with absorption chillers in order to use cheap urban steam. Presumably, as demonstrated in the ADL study[2], use of steam power in large office buildings will decrease in new construction.

The three points plotted as § represent French, Swedish and U.S. national energy consumption which is less than the non-cooling part of the U.S. average. The energy consumption in Sweden, with a cold climate and expensive oil, is slightly less than the French average.

Two other Swedish points are also plotted: Swedish Building Norm 1975 (SBN-75) and Farsta-Folksam 5. SBN-75 represents redesign of an office building, typically triple-glazed, with 25 cm of rockwool insulation, and heat recovery for fresh air, yielding an annual ROI of 12%. Farsta-Folksam represents a new suburban Stockholm building which stores heat by circulating air through hollow cores in the concrete roof/floor slab at no increase in first cost. In this design, total annual site energy consumption has been reduced to 45,000 BTu per ft^2; however, in the most economical DOE-2 run of a 31-story office building, consumption was calculated to be 70,000 Btu per ft^2 and average consumption for U.S. stock is 130,000 Btu per ft^2. These comparisons demonstrate that by careful study of alternative HVAC systems, and by storing heat and coolth, energy consumption in a typical U.S. office building can be reduced by 1/2 to 2/3 with little or no increase in first cost.

The 25-year life-cycle cost (LCC), calculated by using first costs of the HVAC systems plus present values of fuel, electricity and maintenance costs, are tabulated for the seven systems in Table 1.

Annual resource energy consumption for each system is also shown in the table. As can be seen, LCC's for constant air volume systems (CAV) 1,3 and 8 range from $21 to $36 per ft^2, while LCC's for variable air volume systems (VAV) 2, 4, 5 and 6 range from $25 to $27 per ft^2. Since the least expensive system, at $21 per ft^2, is also the least attractive from the point of view of comfort, system 5 repesents the most economical investment with new construction. CAV systems 1 and 3, popular when energy costs were negligible, waste more energy at a correspondingly high expense. Remarkable annual returns on investment (ROI) can be achieved by retrofitting CAV

Table 1. Annual resource energy consumption and Life Cycle Costs for a 31-story office building with conventional primary (boiler, chiller and cooling tower) and different secondary HVAC systems.

System No.	Secondary HVAC System		Annual Resource Energy Consumption		Life Cycle Cost	
			KBTU/ft^2	KWh/m^2	$/$ft^2$	$/$m^2$
1	DD - CAV		238	752	29	312
2	DD - VAV (50%)		181	572	27	291
3	SD - CAV - Reheat		262	828	36	387
4	SD - VAV (50%) - Reheat[a]		184	581	26	280
5	SD - VAV (30%) - Reheat[a]		170	537	25	269
	Interior	Exterior				
6	SD - VAV (10%)	Baseboard[b]	192	607	26	280
8	DD - CAV	Two-Pipe Fan Coil	168	531	21	226

DD = Double Duct, SD = Single Duct
CAV = Constant air volume, VAV = Variable air volume
a. Reheat systems are controlled by space thermostats.
b. Baseboard systems are controlled by outside thermostats.

systems with VAV systems, i.e., converting from system 1 to system 2, or from system 3 to system 4. A retrofit from 1 to 2 costs $30 per mixing box, yielding an annual ROI of 900%; a retrofit from system 3 to 4 costs $350 per mixing box, yielding an annual ROI of 100%.

PLANNED ACTIVITIES FOR 1980

After the completion of DOE-2.1 and its documentation early in 1980, LBL's efforts will be directed toward improving the program in areas recommended by a newly-formed advisory committee and approved by the Department of Energy. This new committee will be comprised of two sub-committees of five members each. One sub-committee consists of practicing building professionals; the other, of computer program theoreticians. In preparing its consensus opinion on program improvement for presentation to the Department of Energy, the committee will consider optimum program structure, the needs of the Department of Energy, and the needs of the user community, as generated by the user survey conducted in FY-1978. The User Coordination Office at LBL will be expanded to respond to the needs of an enlarged user community.

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HOSPITALS PROGRAM

R. Pollack and I. Turiel

INTRODUCTION

As energy-intensive buildings, hospitals have been singled out for special study by Lawrence Berkeley Laboratory's Energy Efficient Buildings (EEB) Program. Energy conservation in hospitals involves a number of special considerations, not only because hospitals are high-intensity users, especially for their HVAC needs (heating, ventilation and air conditioning), but because their patient-care responsibilities place unique demands on the type and level of energy-conserving modifications implemented, or recommended, as general standards nationwide. For example, it is believed that hospital patients are more susceptible than the general population to airborne infections, to the deleterious effects of odors and chemical contaminants, and to changes in temperature and relative humidity. In addition, a significant body of literature substantiates the fact that infections whose onset is in the hospital and which are unrelated to the patient's condition (nosocomia) are associated with the high-risk environment of the hospital itself. Finally, as institutions serving health and medical needs of the general public, complex policy questions are raised more sharply than in other institutional buildings considering energy-conservation-related changes in design and procedures. Thus, the ultimate objectives of the Hospitals Program are 1) to develop energy-conservation strategies that do not compromise the health, safety and comfort of patients and staff, and 2) to support DOE/HEW/LBL efforts to promote energy-efficient ventilation and thermal standards for hospitals.

Because more than 50% of the energy consumed in hospitals is accounted for by their HVAC systems, with lighting and water the next largest consumers, the Hospitals Program has been closely tied to LBL's Ventilation Program. Two subcontracts were awarded by LBL to complete those tasks regarded by Hospitals Program staff as priority needs: 1) the University of Minnesota (School of Public Health) was charged with reviewing current hospital ventilation and thermal standards and recommending opportunities for energy conservation compatible with the health, safety and comfort of the patients and staff; and 2) Hittman Associates, Inc. was charged with studying energy-efficient water use in hospitals.

UNIVERSITY OF MINNESOTA

As an outgrowth of an international working conference presented in February, 1978, the University of Minnesota conducted an opinion poll of panelists to pursue some of the issues that had remained in question and unresolved. The poll listed various factors related to hospital-acquired infections, thermal comfort, odors and toxic chemicals and requested panelists to rank each in terms of their relative importance. The results tabulated thus far indicate that in the area of nosocomial infections, airborne contaminants were rated next to the least important, and techniques related to quality patient care were regarded as more important than hospital ventilation design criteria.

ACCOMPLISHMENTS DURING 1979

A similar poll is now being conducted among members of the Association of Practitioners and Infection Control, an association of 4,500 members, approximately 85% nurses and 15% doctors and other professionals primarily employed as infection control officers. Preliminary tabulation of these returns has corroborated findings revealed by the limited poll of conference panelists. Handwashing was consistently viewed as the most important of the ten factors presented in relation to nosocomial infections, and the importance of airborne contaminants rated 5th or 6th.

In their survey of existing ventilation standards, the University of Minnesota reported that national standards related to hospital ventilation and thermal requirements rely essentially on:

1. U.S. Department of Health, Education and Welfare, Public Health Service, Health Resources Administration: Minimum Design and Construction Requirements under the Hill-Burton Program.

2. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.: Applicable Engineering Standards.

3. National Fire Protection Association: Life Safety Code (NFPA).

In addition, they note the following:

1. Nineteen states adopted their own standards. (ASHRAE).

2. Seventeen states and one territory adopted the Hill-Burton standards.

3. Seven states adopted the NFPA Life Safety Code.

4. Two states adopted an ASHRAE standard.

5. Five states do not have any standard.

Following outside review of its recommended standards and careful analysis of written comments received, the University of Minnesota has developed the following set of principles:

1. Except for those spaces used directly for patient care or where other unusual health or safety hazards exist, ASHRAE energy conservation standards can be applied.

2. Ventilation requirements do not need to be based on control of airborne microorganisms, except for those sensitive areas where the patient is particularly at risk.

3. Acute odors should be controlled at their source, not by ventilation air.

4. An outdoor air requirement for control of the airborne chemical contaminant load needs to be established.

5. Humidity control need not be based on patient comfort or control of airborne micro-organisms.

6. A temperature range can be specified for patient care spaces.

These principles were incorporated in a Draft Discussion Paper: "Modification of Hospital Ventilation and Thermal Standards for Energy Conservation" sent to 500 knowledgeable professionals around the country. A 26% response was received and comments from this group were incorporated in their "Proposed Pressure Relationship, Ventilation and Thermal Requirements of Certain Hospital Areas."

The University of Minnesota also has completed a study of chemical contaminants of hospital air, and their final report[1] is now being reviewed by members of the Ventilation Program staff. Briefly, their findings can be summarized as follows:

1. The general public is misinformed about the quality of sanitation practices in hospitals;

2. Most hospital workers focus, justifiably, on the hazards of chemical contaminants to employees, whose exposure is prolonged in contrast to that of patients whose exposure is short-term.

3. Hospital housekeeping staffs are as much influenced by commercial advertising of chemical products as the general public and restraint in their use is the best answer for both groups.

4. Spot ventilation specifically designed for hospital laboratories should be promoted as a control measure for chemical contamination.

5. Ventilation systems in hospital laboratories should exhaust directly outdoors and, again, be designed according to the heat load generated by the specific instrumentation housed.

The University of Minnesota investigated hospital laundry water use to determine whether the quality of finished laundry with respect to stain removal, whiteness, and sanitation could be maintained under the new (1979) DHEW minimum hot water requirement of 160°F. From their review of the literature, they concluded generally that a water temperature of 140°F or 150°F was adequate for removal of stains as well as for whiteness, as long as the soaps, detergents and bleaches were appropriately used. For example, hospitals generally use medium-titre soaps which dissolve at 130°F to 140°F. In terms of bleaches, water temperatures below 160°F will require a slightly longer immersion time but are otherwise acceptable for assuring stain removal and whiteness.

The problem of transmitting diseases or infections by means of inadequately laundered linens appears to be a real one. Various organisms (Staphylococcus, polio virus, vaccinnia virus and Salmonella typhimurium) can persist on fabrics for days or weeks after contamination first occurs. Apparently, today's standards in this area are based on an early study of Arnold in 1938. In his year-long study of 54 hospitals, Arnold determined a formula that called for 165°F water temperature and the addition of a "sour" to the final rinse as a means of eliminating bacteria. Ironing fabrics also kills most bacteria (see Table 1). A summary table of effective wash temperatures for various organisms is presented in Table 2. From these data (a compilation of 12 reports published since 1938) it seems that a water temperature of 140°F is effective in killing most vegetative organisms and 150° is effective for the remaining.

The University of Minnesota concurs with Hittman's recommendations that carefully controlled studies need to be initiated in a University setting, with input from experts on microbial contamination as well as from health departments and infection control personnel. Their program plan for such a comprehensive project is being reviewed by LBL.

Ultimately, the findings from these foregoing studies must be related to broader policy questions which DOE and HEW will need to consider in meeting uniform standards for efficient use of energy in the nation's hospitals. For example,

- Hospital staff and administrators must be made aware of energy conservation opportunities and must be given access to the technical knowledge needed to implement changes;
- A financial environment must be created that effectively removes institutional barriers to energy conservation;
- The progress of energy management in hospitals must be monitored to determine what additional assistance is needed to produce effective conservation programs;
- Energy-related design and operating standards which are unnecessarily restrictive must be re-evaluated and changed, where appropriate, to allow energy-efficient operation.[5]

HITTMAN ASSOCIATES, INC.

The scope of work assigned to Hittman Associates was as follows:

1. Define water and water heating energy use in hospitals with respect to functional areas, e.g., diet kitchen, cafeteria, laundry, etc.
2. Review existing and proposed energy conservation measures for diet kitchen and laundry hot water.
3. Survey existing and proposed methods for energy-efficient water use with emphasis on diet kitchen and laundry applications, and review standards and regulations.

Preliminary work accomplished in these areas by Hittman Associates is reported in LBL's Annual Report for 1978.[2] The results of their continued study of hospital use of water in laundry and diet kitchen areas were published in July 1979 as an LBL report, Energy Efficient Water Use in Hospitals, Final Summary Report. The authors note that the data reported reflect criteria based on commercial acceptability factors, and recommend strongly that a research program be developed based on broad-based statistical sampling, using criteria that meet scientific standards for determining energy-efficient use of water in prototypic hospital settings.

Recommended for immediate implementation by hospitals are the following, none of which involves major expenditures:

- Comprehensive maintenance programs
- Laundry formula and equipment upgrading
- Use of 160°F water in laundries
- Use of cold water in floor and bathroom cleaning and dishwasher prerinse
- Use of low temperature water in dishwashers
- Reduction of water flow rate in X-ray film processing to two gallons/minute and/or install demand-only film processors
- Lowering of supply water temperature to 120°F
- Investigate the benefits of installing a laundry water heat reclaim system.

Hittman's investigation of federal, state and local health codes and standards related to hospital laundries and diet kitchens revealed great variability, which they regard as added reason for a comprehensive research program that would provide universally acceptable methods for contamination control in hospital procedures.

Table 1: Effectiveness of drying and ironing in destroying bacteria.

A. Drying

Organism	Conditions	Log reduction in counts	Source
E. coli T3 phage	115°F[a] (washed at 100°F)	1.69[b]	Wiksell et al., 1973
Serratia marcescens	115°F[a] (washed at 100°F)	3.84[b]	Wiksell et al., 1973
S. aureus	115°F[a] (washed at 100°F)	3.23	Wiksell et al., 1973
S. aureus	185°F for 30 min.	b	Spillard, 1964
B. stearothermophilus	115°F[a] (washed at 100°F)	0.78	Wiksell et al., 1973
M. pyogenes (S. aureus)	160°F for 30 min.	1.78	Ridenour, 1952
M. pyogenes (S. aureus)	151°F for 15 min.	0.70	Ridenour, 1952
S. aureus	(washed at 100°F)	2.36	Walter & Shillinger, 1975
Klebsiella pneumoniae	(washed at 100°F)	0.59[b]	
Undentified	180°F for 25 min.	b	Johnston, 1958
Clostridium butyricum	185°F for 30 min.	b	Spillard, 1964
E. coli	185°F for 30 min.	b	Spillard, 1964
Pseudomonas arginosa	185°F for 30 min.	b	Spillard, 1964

B. Ironing

Organism	Conditions	Log reduction in counts	Source
Bacillus subtilis	a	b	Arnold, 1938
B. welchii	a	b	Arnold, 1938
B. megatherium	a	b	Arnold, 1938
B. coli	a	b	Arnold, 1938
B. pyocyanus	a	b	Arnold, 1938
Streptococcus sp.	a	b	Arnold, 1938
Staphylococcus sp.	a	b	Arnold, 1938
M. pyogenes	twice at cotton setting	3.91	Ridenour, 1952
Mainly S. aureus	350°F	0.4 to 1.4	Church & Loosli, 1953
Unidentified	338°F for 1 min.	b	Johnston, 1958

[a]Details not further specified.

[b]Authors report no survivors.

Table 2. Reduction in counts of microorganisms after washing at various temperatures.

Organism	Wash Temp. (°F)	Time	Log reduction in counts	Source
Unidentified	165°	27 min.	>5[a,b]	Arnold, 1938
E. coli T3 phage	154°	c	4.41	Wiksell, et al., 1973
Serratia marcescens	135°	c	5.19[a]	Wiksell, et al., 1973
Staphylococcus aureus	135°, 155°	c	4.5	Wiksell, et al., 1973
Staphylococcus aureus	77°, 20 ppm Cl	c	>6	cited in Foter, 1960
Staphylococcus aureus	140°	5 min.	6.18[a]	Walter & Schill-inger, 1975
Staphylococcus aureus	140°	5 min.	>5	pers. comm.
Staphylococcus aureus	141°	5 min.	>5	Crone, 1958
M. pyogenes var. aureus (S. aureus)	140°	1 min.	4.27	Ridenour, 1952
M. Pyogenes var. aureus (S. aureus)	100°, 5 ppm Cl	15 min.	>4	Ridenour, 1952
E. coli	140°	1 min.	4.32	Ridenour, 1952
E. coli	100°, 100 ppm Cl[d]	5 min.	2.33	Ridenour, 1952
B. stearothermophilus	154°	c	1.71	Wiksell, et al., 1973
B. stearothermophilus spores	160°	15 min.	2.7	Ridenour, 1952
Polio virus	130°	10 min.	(no virus recovered)	Jordan, et al., 1969
Polio virus	110°, 200 ppm Cl	10 min.	(no virus recovered)	Jordan, et al., 1969
Polio virus	129° to 140°	c	>4.6	Sidwell, et al., 1971
Coliforms	123°, 15 ppm Cl	13 min.	4[a,b]	Sandiford, et al., 1959
Coliforms	140°	13 min.	>6[a,b]	Sandiford, et al., 1959
Streptococcus faecalis	149°	5 min.	>7	Jerram, 1958
Chromobacterium prodigiosum	140°	5 min.	>7	Jerram, 1958
Klebsiella pneumoniae	120°	13 min.	5.28	Walter & Shill-inger, 1975

[a]Authors report no surviving bacteria.
[b]Counts in final rinse water.
[c]Time not specified.
[d]Not under actual washing conditions; washing E. coli seeded swatches produced 99.99% (4 log) reduction by removal by mechanical action alone.

PLANNED ACTIVITIES FOR 1980

Final recommendations for revising ventilation and thermal standards for hospitals will be submitted in FY 1980.

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ENERGY EFFICIENT WINDOWS PROGRAM

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INTRODUCTION

Approximately 20% of the annual energy consumption in the United States is used for space conditioning of residential and commercial buildings, and about 25% of that figure is required to offset heat loss and gain from windows. In other words, 5% of national energy consumption, 3.5 quads annually, or the equivalent of 1.7 million barrels of oil per day, is tied to the thermal performance of windows.

An important aim of the Windows Program is to develop and commercialize innovative and effective window designs, materials and accessories that support national energy conservation goals. Of critical importance to our program is that design professionals and the public-at-large recognize, accept and use these products. To that purpose, we have developed a broad-scale program encompassing research and development activities, field demonstrations, market studies and an education and public information program. While the technical management of these projects is the responsibility of the Windows Group, certain portions of the work are subcontracted out.

ACCOMPLISHMENTS DURING 1979

The work accomplished in FY 1979 comprises three major areas: (1) program planning and management, (2) performance testing and analysis, and (3) design strategies, materials, and prototype developments. Projected activity for 1980 is included in the detail presented below.

Program Planning and Management

The Windows Program Plan is being developed to outline and coordinate all DOE-supported energy conservation activities related to windows, and will interface with the DOE Thermal Envelopes and Insulating Materials Program Plan and the Passive Solar Program Plan. Substantial efforts were made in 1979 to better coordinate with the DOE Passive Solar Program to avoid unnecessary duplication of effort. As a result of this activity, several joint programs are in progress or under discussion.

In our continuing concern that research activities have commercial potential and applicability, we have looked in detail at several subsectors of the window accessories market to understand the relationships between product manufacturers and the distribution and sales networks that provide building designers and managers as well as homeowners with product selections. Our immediate next concern is that technical data and non-technical information on energy-conserving window designs be readily transmitted to relevant professionals. To this end, we developed a publication, "Windows for Energy-Efficient Buildings," which reports on latest developments, patents, new materials and products, legislation, etc., and is circulated widely to architects, engineers, manufacturers, inventors, suppliers, code officials, and researchers. In the process of generating material for this publication, extensive product files, patent files, bibliographies and related information resources have been compiled.

Performance Testing and Analysis

Thermal Performance Testing. We have set up a Building Technology Laboratory in the College of Environmental Design of the University of California, Berkeley, to support our research and development activities, to provide independent tests and evaluations of materials and products submitted by subcontractors, and to permit evaluation of new products being introduced to the market. Testing facilities include a calibrated hot box (shown in Fig. 1), which is now being used to test the thermal performance of

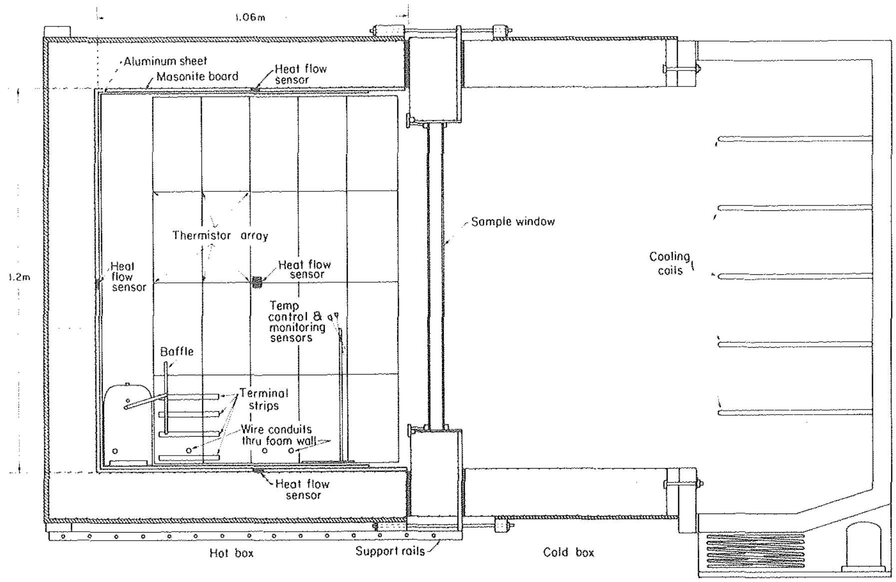

Fig. 1. Section through calibrated hot box showing hot and cold box chambers and sample window. (XBL 799-2921)

windows and associated energy-conserving accessories. Sample results are shown in Fig. 2. Infiltration tests on windows can now be made in our laboratory with the apparatus shown in Fig. 3. The heat loss and heat gain rate of windows can be improved with the use of thin-film coatings on glazing materials. We now have capabilities for measuring a range of optical properties of glazing materials and coatings, and additional measurement capabilities will be added in 1980. A solar calorimeter for measuring the solar heat-gain properties of windows is under construction and should be completed in FY 1980.

A major goal of our program is to develop and promote managed window systems, i.e., windows whose thermal/optical properties can be manually or automatically changed by building occupants. The laboratory testing facilities described above were designed primarily to conduct steady-state measurements of static materials and devices. Accordingly, we are designing a Mobile Window Thermal Test (MoWITT) facility to test the performance of managed window systems (see Fig. 4). As conceived, such a facility will permit the testing of net thermal performance of windows (combined infiltration, conduction/convection, radiation effects) as a function of window orientation and changing weather conditions throughout the day. Winter testing will be conducted in a cold, mountainous location and summer testing in a desert area. The thermal properties of each of the four test chambers in the MoWITT facility can be varied in terms of insulation level, thermal mass, and air-leakage rate, enabling us to simulate a wide range of building conditions. From these experimental results, we will be able to rank the performance of various window-management strategies as well as validate our analytical models. Working drawings for the MoWITT facility are nearing completion, and construction is scheduled for late 1980. Development of software for its data-acquisition system is in progress.

Analysis and Computer Modeling. A detailed analytical model of the net heat transfer through a window assembly composed of an array of glazing elements and optical coatings was also developed this year. This model will also predict the performance of multiple-glazed windows in which the airspace has been filled with a low-conductivity gas. Additional capabilities will be added in the coming year.

A computer model for calculating optical constants for a variety of multilayer optical films was also completed. We calculated the spectral properties of various coatings in order to generate optical coefficients for analysis of visible and solar radiation transmission through windows, as well as thermal transfer between glazing layers.

In order to determine the effectiveness of window-management strategies, the performance of the window must be assessed in the context of the performance of the entire building. For these studies, we have used the Building Energy Analysis Program (DOE-2), modified to incorporate a variety of window management strategies such as movable shades and shutters and to provide detailed quantitative information on the hourly performance of windows and a more qualitative graphic perspective of the net gains and losses of windows on an hour-by-hour basis over the year. The performance of a variety of movable insulating devices for windows has been calculated by means of this model. Figure 5 shows the annual heating loads of a house in

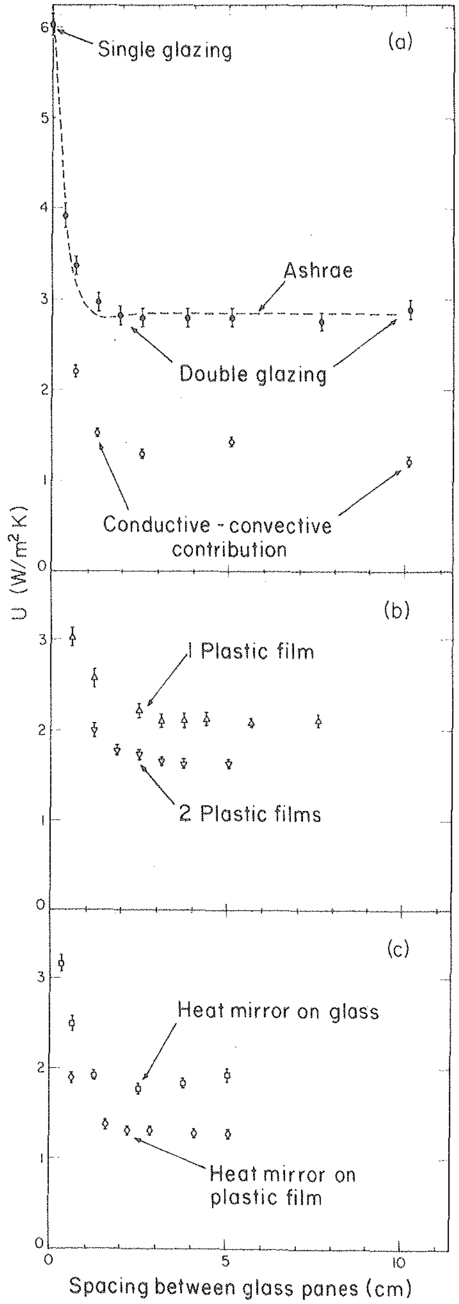

Fig. 2. Sample Thermal Transmittance vs. Glass Spacing for the Prototype Windows. (XBL 799-2917A)

a) Ordinary double glazing (solid points) and double glazing with aluminum foil on inside of both glass panes (open circles).

b) Double glazing with one (triangles) or two (inverted triangles) plastic films.

c) Double glazing with heat mirror coating on plastic film, where the plastic film is mounted on the surface of one glass pane (squares) or suspended between panes (diamonds).

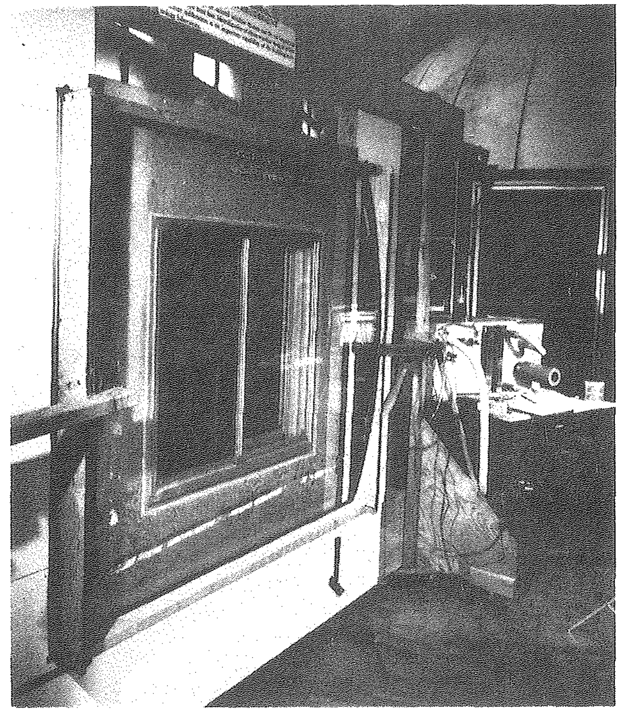

Fig. 3. View of apparatus for measuring air leakage of windows. (CBB 793-3731)

Minneapolis whose single- and double-glazed windows were fitted with a variety of insulating coverings that were closed for 12 hours each night. The effects of window orientation, window area, hours of operation and air-leakage characteristics of the window coverings may be just as important as the insulating value in determining annual energy savings. The foregoing studies are concerned with winter performance; in FY 1980, we will extend this work to include the effect of movable shading devices on cooling loads.

Design Strategies, Materials, Prototype Developments

Daylighting. Windows and skylights provide visible daylight in buildings, thus reducing lighting energy and peak power requirements. In addition, natural lighting has always been valued by architects and building occupants for qualitative reasons. In FY 1979, our daylighting program activities were significantly expanded.

In order to predict annual energy savings, data on daylight availability (including the frequency and intensity of daylight) must be collected. No source for such data currently

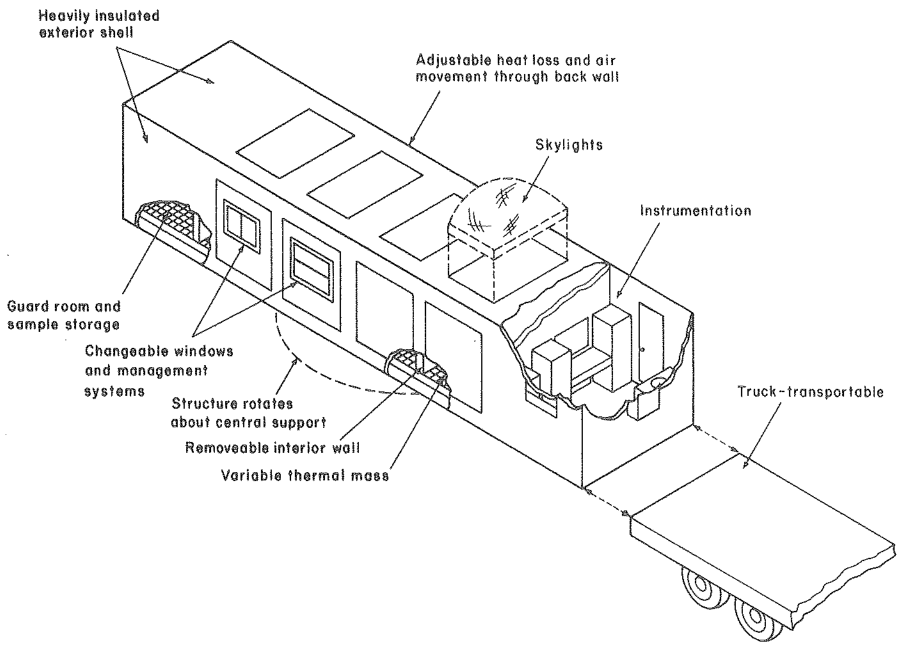

Fig. 4. Schematic view of Mobile Window Thermal Test (MoWITT) facility. (XBL 796-1848)

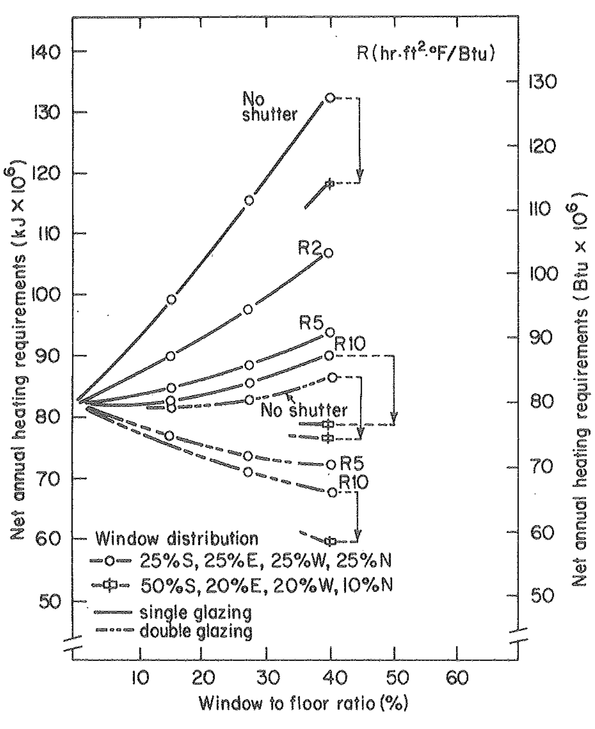

Fig. 5. Annual heating energy requirements for a house in Minneapolis based upon various glazing and insulating shutter options. (XBL 796-10097)

exists for most of the United States. The Pacific Gas & Electric Company Building in San Francisco has been instrumented to collect and record the amount of solar and visible radiation available at all building surfaces. An array of thirteen pyranometers and photometers has been installed to feed readings to a data-acquisition system at fifteen-minute intervals (see Fig. 6). Preliminary results for the first year of monitoring suggest strong linear correlations between illumination and insolation -- a finding which encourages us to believe that daylight availability data can be generated from existing measurements of solar radiation. A generalized method for developing illumination availability data from insolation is being developed.

Accurate and efficient daylighting design methods must be conveyed to building designers if they are to successfully incorporate daylighting designs in buildings. Three different approaches are in progress as part of the overall LBL program in this area: Under subcontract, Renssallear Polytechnic Institute is developing a computer program to predict daylight illumination in interior spaces; a team at the University of Washington is developing a graphic design method which employs transparent overlays for daylight predictions; and, finally, an LBL project is underway to simplify design techniques (computational and graphic) for predicting daylight illumination from clear and overcast skies (Fig. 7). Activity in these

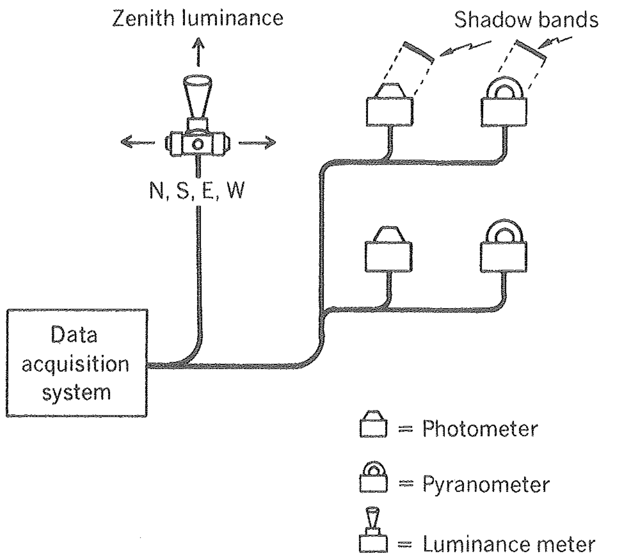

Fig. 6. Schematic of rooftop photometric and radiosensor array for determining insolation/illumination correlations. (XBL 796-10182)

areas will continue in 1980 and a small effort to add daylighting analysis capabilities to a building energy analysis program (DOE-2) will be expanded.

Physical models are useful for studying alternative daylighting systems. To facilitate these studies, an artificial sky dome has been designed and built on the U.C. campus (Fig. 8). Luminance distributions for both clear and overcast skies will be reproduced on the underside of the hemisphere; by measuring light levels in a scale model building under this "artificial sky," we will be able to predict actual values expected in a real building. The addition of the lighting control system and an associated photometric measurement system in 1980 will make the artificial sky fully operational.

Direct sunlight is the only natural light source with sufficient intensity and collimation to illuminate interior spaces deep in the building, and various design approaches have been studied to exploit beam daylighting in buildings. Over the past two years we have examined

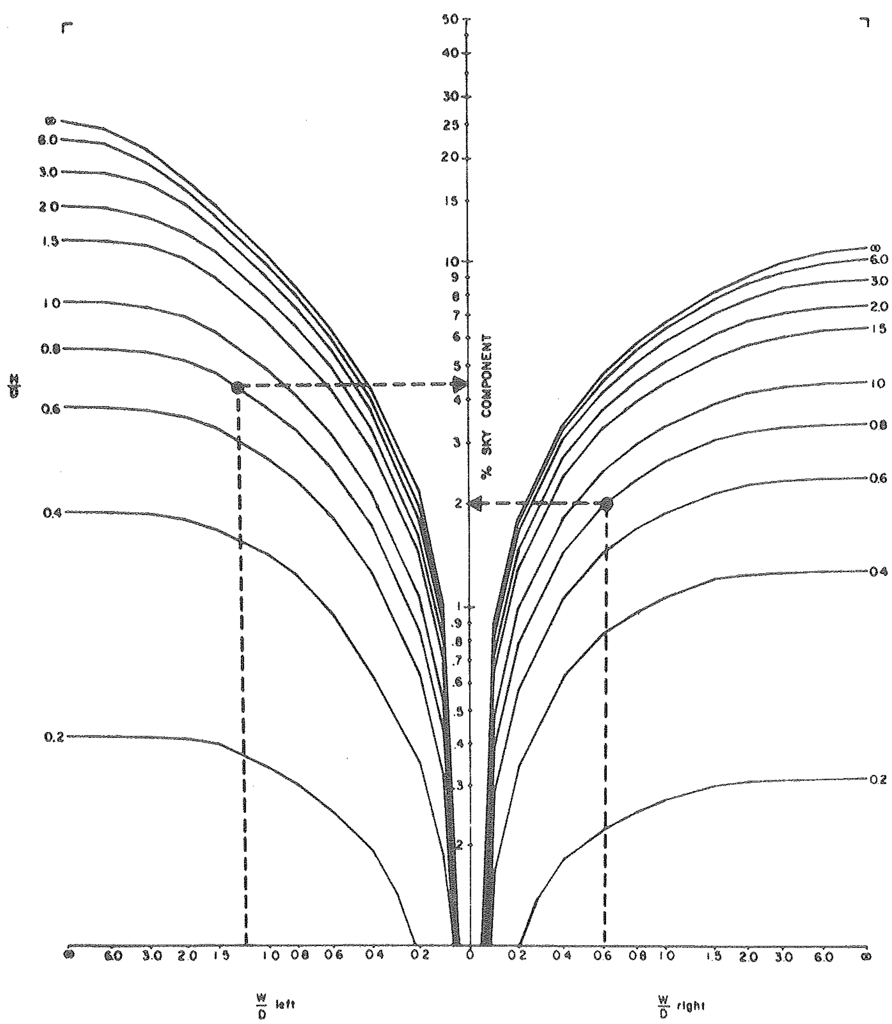

Fig. 7. Graph for determining sky component of daylight factor for clear sky conditions, sun altitude 40°. (XBL 803-8642)

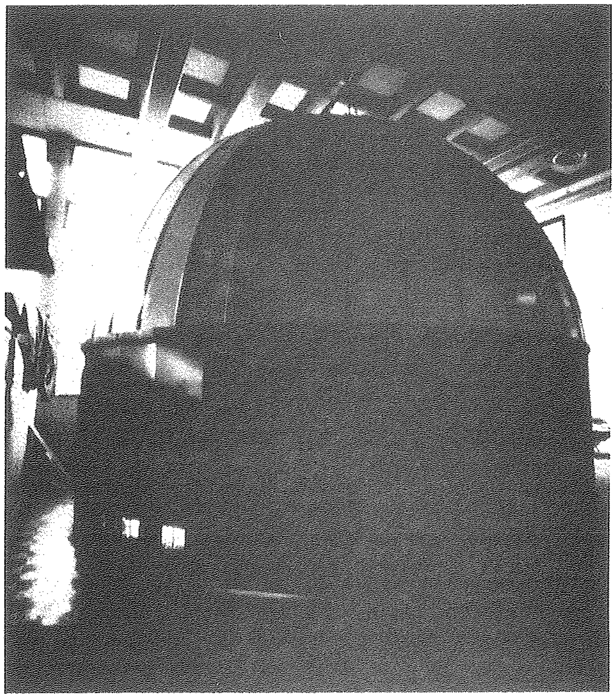

Fig. 8. Exterior view of artificial sky dome for daylighting studies. (CBB 803-2837)

the feasibility of using reflective devices mounted at the windows to take advantage of direct sunlight. In 1979, attention turned to using linear fresnel lenses as a possible alternative to mirror systems. Computer simulation and model testing in this area will continue in 1980.

We believe that daylighting techniques would be more widely used by architects and builders if technically accurate information was more accessible to them. For this reason, LBL has taken a lead role in developing a comprehensive educational program to fill this gap. A draft of our "Daylighting Resource Package," directed to educators and building designers and prepared in collaboration with the Illuminating Engineering Society, several universities, and daylighting experts throughout the country, will be available in summer, 1980. Over the next two years, the resource package will be refined, expanded, and disseminated widely.

Heat Mirror Commercialization. A transparent heat mirror is an optical coating applied to a glass or plastic glazing material that transmits the full solar spectrum but reflects long-wave infrared radiation emitted by room temperature surfaces. By reducing the radiative component of thermal losses, the heat transfer coefficient of a single- or double-glazed window is greatly reduced.

The development of transparent heat mirror coatings for plastic films has been successfully undertaken by subcontractors, although abrasion and corrosion resistance of the deposited coatings remains a problem area. It is possible that heat mirrors may find their first use in sealed airspaces of new windows rather than as retrofits to single-glazed windows, as originally envisioned. For new windows, the coating can be deposited directly on glass or on plastic films which are then glued to the glass surface or stretched across the double-glazed airspace.

We have examined various window configurations incorporating multiple glass, plastic and coating layers (Fig. 9). Note that the best of the heat mirror window systems has a U-value approaching that of a well-insulated wall. A number of prototype window systems incorporating heat mirrors in different configurations were fabricated and tested in our calibrated hot box. The experimental results agree well with our computational models. We are currently planning to install prototype windows incorporating heat mirrors in test buildings to monitor their performance under field conditions. In 1980, we expect that several firms may be ready to introduce these heat-mirror windows to the market.

Convection-Suppression Window Prototypes. Double-glazed windows frequently incorporate venetian blinds or similar devices between the glass panes to control light and glare as well as to provide privacy. These devices also help to reduce heat loss, although they have not been designed for that purpose. The Mechanical Engineering Department at the State University of New York, Stonybrook, is investigating the design and performance of mechanisms installed in the air space of double-glazed windows to suppress convective heat transfer (see Fig. 10). It appears that this modification of double-glazed windows may yield a heat-transfer rate approximating that of an insulated wall. Prototypes of such devices with a thermal resistance of R5 in an open mode and R10 in a closed mode have been built and tested. A heat-transfer gauge with a cross section of approximately 20 ft^2 was built so that full-sized windows could be tested. Interferometric techniques were used to examine heat transfer in the airspaces created by the parallel slats. Initially, ideal airspaces, i.e., with no air leaks, were examined. When the slat-to-glass clearance was increased to as much as 1/8 inch, the heat-transfer rate was not seriously increased. These results suggest that building products with a comparable level of thermal performance could be successfully manufactured.

Triple and quadruple glazing systems will further reduce heat loss through windows although solar gain may be sacrificed due to surface reflection losses. Replacing window glass with a thin plastic film coated to be anti-reflective solves this problem effectively. These lightweight, high-performance window systems have been studied by means of computer simulation, and prototypes tested in our laboratory show good agreement with the model. Although the performance of these systems does not match that of multi-glazed units incorporating transparent heat mirrors, they are not as susceptible to corrosion as units using heat mirrors.

	TOTAL GAP (cm)	ε	SURFACE	GAS	ΔT (K)	SOLAR TRANSMITTANCE	U (W/m²·K)	CALCULATED OR MEASURED	SOURCE (Ref)
DOUBLE GLAZED WINDOW	.6	.065	3	Air	10	--	2.7	meas.	Glaser (19)
	1.2	.065	3	Air	10	--	1.8	meas.	Glaser
	1.2	.065	3	Krypton	10	--	1.0	meas.	Glaser
	1.6	.065	3	Air	10	.45 visible (est	1.6	meas.	Glaser
	2.0	.1	3	Air	20	.37 visible	1.5	calc.	Karlson & Ribbing (34)
	1.2	.15	3	Air	--	--	1.9	calc.	Rallio (16)
	1.27	.20	3	Air	22	.70	1.99	calc.	(ASHRAE Data)
	1.27	.05	3	Air	22	.63	1.70	calc.	(ASHRAE Data)
	1.2	.06 (est	3	Low Cond	--	.15-.49	1.4-1.5	meas.	Flachglas literature
	.64 - 1.27	low	3	Air	22	.04-.3	1.7-2.8	meas.	Commercially Available
	1.2	.1-.2	3	Krypton	19	--	.9	calc.	Kostlin (14)
	1.27	.05	3	Krypton	18	--	1.18	calc.	Silverstein (18)
DOUBLE GLAZED WITH SINGLE PLASTIC INSERT	3.8	.20	3,4	Air	--	.59	.89	calc.	Johnson (36)
	2.54	.05	4	Air	10	.56	1.19	calc.	
	1.8	.05	4	Air	10	.56	1.43	calc.	
	1.8	.05	4	Argon	10	.56	1.33	calc.	
	1.8	.05	4	Krypton	10	.56	.87	calc.	
	1.8	.20	4	Air	10	.63	1.60	calc.	
	2.54	.05	5	Air	10	.50	1.01	calc.	
	1.8	.05	5	Air	10	.50	1.25	calc.	
	1.8	.05	5	Argon	10	.50	1.15	calc.	
	1.8	.05	5	Krypton	10	.50	.72	calc.	
	1.8	.20	5	Air	10	.56	1.52	calc.	
DOUBLE GLAZED WITH DOUBLE PLASTIC INSERT	3.8	.05	7	Air	10	.46	.49	calc.	
	1.8	.05	7	Air	10	.46	1.24	calc.	
	1.8	.05	7	Argon	10	.46	.97	calc.	
	1.8	.05	7	Krypton	10	.46	.64	calc.	
	3.8	.05	3,6	Air	10	.42	.44	calc.	
	1.8	.05	3,6	Air	10	.42	1.24	calc.	
	1.8	.05	3,6	Argon	10	.42	.96	calc.	
	1.8	.05	3,6	Krypton	10	.42	.61	calc.	

Fig. 9. Thermal performance characteristics of various high performance window designs. (XBL 796-10098)

Movable Insulation. We have calculated and measured the thermal performance of a large number of movable insulation systems for windows. (Some results are described in the Analysis and Computer Modeling Section.) Calculations and laboratory measurements are now being supplemented with large-scale field testing of products in buildings.

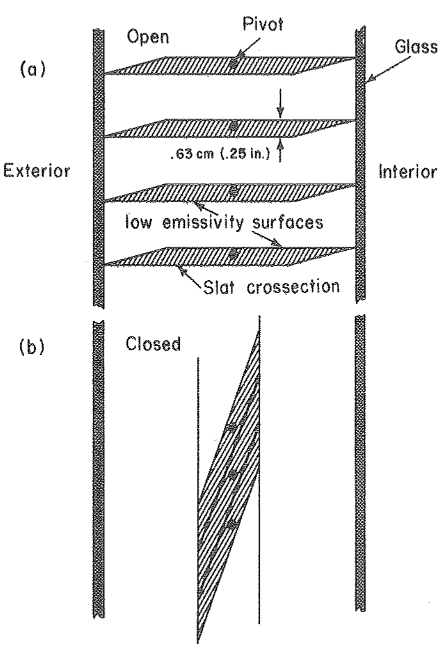

Fig. 10. Schematic cross-section of open and closed convection suppression window prototype. (XBL 796-1099)

The Insulating Shade Company in Branford, CT, has developed a multilayer, aluminized plastic roll-up shade with a thermal resistance of 12 in its deployed mode (Fig. 11). Two hundred such shades have been installed in a college dormitory, and energy savings are being monitored by means of a data-acquisition system designed and built at LBL. Patterns of occupant use of these shades will be studied and attempts may be made to motivate occupants to use the insulating devices more effectively.

Selective-Reflectance Coatings. Reflective and/or tinted glass is widely used in many commercial buildings to reduce solar impact and, thus, energy requirements for air conditioning. However, this glazing will also reduce the amount of daylight illuminating interior spaces and thus increase energy used for electrical lighting.

Since approximately one-half of the sun's radiation is short-wave infrared, which contributes nothing to illumination, an optical coating that selectively reflects this infrared but transmits visible light could, ideally, reduce cooling loads by 50% without reducing available illumination. Under subcontract, Kinetic Coatings, Inc., has used novel ion-beam sputtering techniques to produce durable, weather-resistant selective coatings that can be applied to the outside of a window where they function effectively in a solar-control mode. A wide range of selective-reflectance coatings and protective layers has been produced and tested for both optical performance and weatherability (Fig. 12). In 1979, Kinetic Coatings, Inc., focussed their efforts on scaling-up the sputtering deposition system to provide coating uniformity over a larger sample size. Results to date show a uniformity of ± 5% in optical properties over a

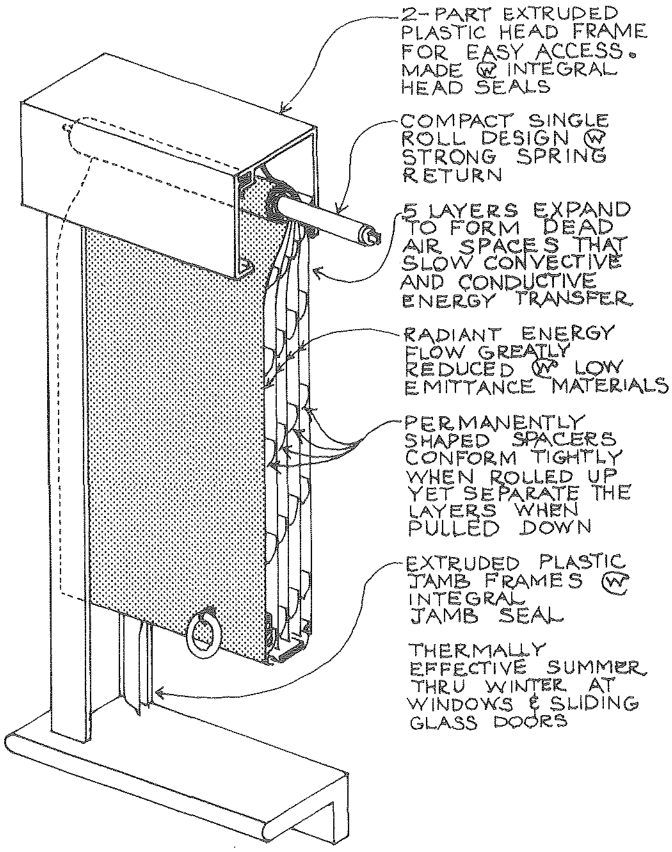

Fig. 11. Cross-section of multilayer insulating window shade. (XBL 803-8641)

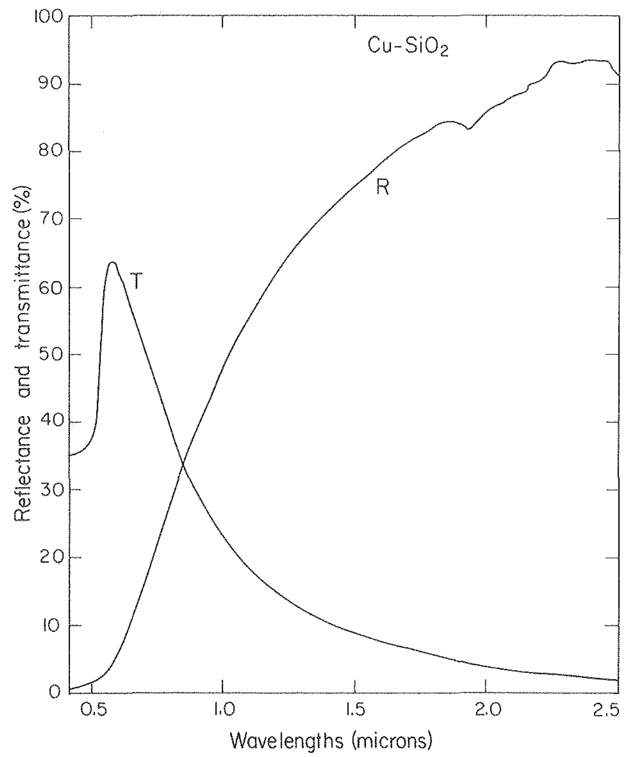

Fig. 12. Normal spectral transmittance and reflectance of selective solar control film with increaed visible transmittance; glass substrate (1/8") - Cu (78A) - SiO_2 (500A); weighted spectral averages, T solar = 42%, T visible = 60%. (XBL 792-512)

1.5 ft^2 area. Indications are that these methods can be further refined so that glass of architectural size can be coated with equal or better uniformity.

High-Performance Sun Control Systems. Conventional venetian blinds are reasonably successful in reducing solar heat gain through windows. To improve their performance, Stevens Institute of Technology in Hoboken, NJ, is testing and evaluating a new class of highly reflective venetian blinds expected to transmit 50% less summer heat than conventional blinds. Test results from this program will be compared with existing methods of calculating the performance of blinds.

Air-Flow Window Systems. Among the options being studied for high-performance window systems are those designed to control heat transfer by using air flow between multiple panes of glazing. These systems offer thermal performance advantages in winter (by reducing net heat losses through the windows and collecting useful solar gain) and in summer (by reducing cooling loads) without sacrificing daylighting potentials year-round.

One such window system of interest to our program is the "Clearview" solar-collector window developed by researchers at the Environmental Research Laboratory (ERL) at the University of Arizona. Designed for residential applications, this window system is being analyzed in detail by ERL for its performance capabilities, and will be field-tested in the upcoming heating and cooling season.

Another approach to designing air-flow windows has been used in Europe for many years. Windows are constructed with cavity ventilating ports that permit air to pass between double or triple glazing at rates controlled by HVAC system pressures (Fig. 13). Venetian blinds in the glazing cavity absorb the sun's heat in the winter and the air flow over the blinds carries the heat throughout the building. Similarly, the heated air can be exhausted from the building in summer to reduce cooling loads. This approach lends itself to many different system configurations that will be investigated by the University of Utah under subcontract. The performance of exhaust air windows and conventional multiple glazed windows will be compared, side-by-side, in a test building designed to rotate so that all window orientations can be evaluated. Test results will be used to assess their marketability in the United States.

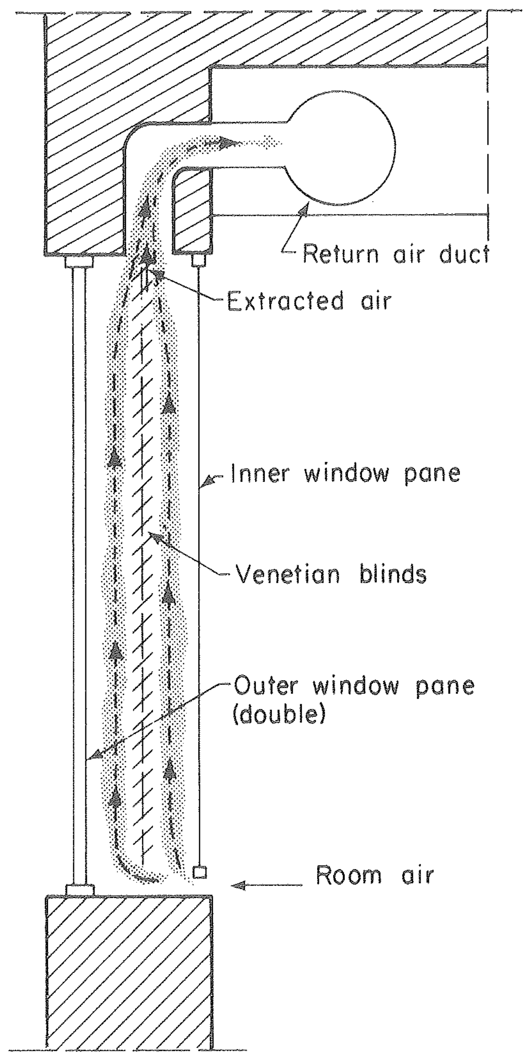

Fig. 13. Schematic cross-sections for air-flow window system. (XBL 7912-13366)

ENERGY EFFICIENT LIGHTING PROGRAM

S. Berman, R. Clear, J. Klems, F. Rubinstein, S. Selkowitz, and R. Verderber

INTRODUCTION

The Energy-Efficient Lighting Program of the Lawrence Berkeley Laboratory is carrying out comprehensive research, development, and demonstration activities emphasizing the commercialization of energy-efficient and cost-effective lighting.

Lighting accounts for 25% of the electrical energy generated in this country every year or about 6% of total energy consumption. This amounts to some 440 billion kilowatt-hours of electricity, which may be broken down by end-use as follows:

	Percentage
Residences	20
Stores	19
Industry	19
Offices	10
Outdoors	8
Schools	7
Streets and highways	3
Other indoor uses	14

We estimate that approximately 50% of the electrical energy consumed for lighting, or about 12% of total electrical sales, could be saved by replacing existing lighting with energy-efficient lighting. This changeover is timely, given the widespread concern about the rising cost of electrical energy. Furthermore, the rapid turnover in most lighting stocks is conducive to the substitution of new, more efficient products.

The broad objectives of our program are:

1. To foster the development of energy-efficient lighting technologies, strategies, and design methods by helping the lighting community (product manufacturers, design firms, professional organizations, and government agencies) to achieve energy-efficient lighting.

2. To minimize any possible adverse social, economic, and environmental impact connected with introducing energy-efficient lighting technologies and lighting-design practices.

3. To provide information so that lighting users, designers, and purchasers can make informed choices on lighting effectiveness and cost/benefit.

4. To assist in removing institutional barriers to adopting efficient lighting.

An important activity of the Energy-Efficient Lighting Program is to make the public aware of LBL's commercialization efforts. We provide information by distributing reports, giving public addresses, and holding meetings, and by maintaining contacts with private persons and many public and professional organizations concerned with lighting.

Among the more prominent organizations with whom we regularly exchange information are the Illuminating Engineering Society, the Institute of Electrical and Electronic Engineers, the American Institute of Architects, the American National Standards Institute, and the Underwriter's Laboratory. As for consumer organizations, we have contacts with trade associations such as the Building Owner's Management Association and government purchasing groups such as the General Services Administration. Most of our information comes from research and development carried out by subcontractors, by the LBL Lighting Laboratory, and by the demonstration projects managed by LBL.

Prior to 1979 we worked primarily on developing new lighting technologies for the commercial and industrial sector. In 1979 we extended our work to the residential sector. The technologies being developed are described in the following paragraphs.

ACCOMPLISHMENTS DURING 1979

High-frequency Solid-state Fluorescent Ballast

The two-and-a-half-year project on developing high-frequency solid-state fluorescent ballasts for the two 40-watt T-12 lamps is expected to be completed this year. The ballasts were developed for LBL by Stevens Luminoptics and IOTA Engineering, and have been used successfully for over a year and a half in a demonstration project at the Pacific Gas and Electric Company (PG&E) headquarters office building in San Francisco. The ballasts reduced energy consumption for in situ lighting by at least 25% and operated safely and reliably, causing no discomfort to users. In 1980, small quantities of these solid-state electronic ballasts will be available for purchase, and stocks will be built up rapidly in the following years. A summary report on the demonstration data was presented at the International Illuminating Engineering Society meeting in Japan in August 1979. The general lighting community concurs with LBL that the project has been a success.

Complementary to the work of the lamp industry, a test of standard fluorescent lamp life has been carried out in the LBL Lighting Laboratory (located in Wurster Hall at the University of California, Berkeley), and the positive result has advanced the commercialization of the electronic ballast. The fluorescent lamps driven by the Stevens ballast are still functioning properly after 12,000 hours of testing, confirming that operation at high frequencies will not shorten lamp life.

Efficient Fixtures

The successful work on the electronic ballast stimulated an attempt to develop an energy-efficient fixture that would take advantage of the lighter-weight ballast and use coatings to increase transmission and reflection abilities.

A lighting fixture has a pronounced effect on the overall efficiency of a lighting system by virtue of its coefficient of utilization. One way of raising the coefficient is to increase the useful light delivered by a fixture by improving the reflectivity and transmissivity of reflectors and lenses. The Optical Coating Laboratory, Inc., under contract to LBL, has applied multilayered, thin-film coatings to reflectors and lenses to see how the coatings would affect fixture performance. Two types of high-intensity-discharge (HID) fixtures have been designed, one for outdoor and one for indoor use. The outdoor fixture employs a high-pressure sodium lamp and the indoor fixture a metal halide lamp. The fixtures have been tested for efficiency with and without the thin-film coatings; results are given in Table 1.

Table 1. Reflectance of Coilzak(R) specular lighting sheet with and without optical coatings.

(Percentage)				
	Single reflection		Multiple Reflections	
	Hemispherical			
	Total**	Specular**	2nd	4th
Coated	94	92	85	72
Uncoated	83	78	61	37

*Dian TR-1 Reflectometer
**Cary 14 Spectrophotometer
(R) Alcoa Trademark

For a single reflection, the reflectivity of the coated Coilzak(R) improves by more than 10%. For multiple reflections (very common in fixtures), the improvement is more than 50%. According to Lighting Science, Inc., an independent testing laboratory, the improved performance increases the coefficient of utilization as follows:

Reflector	Lens	Coefficient of Utilization (%)
Uncoated	Uncoated	63.55
Coated	(No lens)	79.73
Coated	Coated	75.42

In further studies, we intend to determine the cost-effectiveness of the coating procedure.

Residential Adaptive Circline Fluorescent Lamps

LBL awarded a contract to the EETech Corporation to develop a solid-state ballast for the operation of a circline fluorescent lamp. The system will be packaged with an Edison-type base so that it will fit standard residential incandescent light-bulb sockets.

The ballast circuit has been designed to be manufactured as an integrated circuit, which will reduce the size, weight, and cost of the ballast. The light output is equivalent to that of a 150-watt incandescent bulb (2,200 lumens). In addition, the ballast permits the fluorescent lamp to be dimmed to accommodate different lighting needs.

EETech has delivered eight ballast-lamp systems to LBL. Table 2 compares the performance of the EETech system using the electronic ballast with other circline lamps operated with commercial core-coil ballasts and incandescent lamps. As indicated, the EETech design is >10% more efficient than the core-coil types.

Note: The lamp designations may be decoded as follows: "FC" is circline fluorescent; "12," "6," "10," is the lamp diameter in inches; "T10," "T9" is the diameter of the lamp tube in one-eighth inches (i.e., 10/8 inches); "ww" means warm white color; and "sw" means soft white color. The second set of data (in parentheses) for the EETech system shows its performance when dimmed.

Figure 1 shows two photos of the adaptive circline lamp and ballast fitted into the ceiling socket for a standard incandescent lamp. Once the diffuser is in place (Fig. 1b), the occupant cannot tell whether the lamp is fluorescent or incandescent. Compared to the incandescent lamp, the circline fluorescent improves efficiency by more than 60%.

Switching and Controls

Few buildings today have lighting-control systems; yet the energy savings that could be achieved if controls were used is estimated at over 50%. Our objective is to compare the performance and cost-effectiveness of several systems and to publicize our findings. We anticipate that the widespread commercialization of control systems--those available today as well as those still in the research and development stage--will gain in importance and that demand for these systems will increase as their usefulness becomes known.

LBL has organized two demonstrations to assess the energy savings of different switching and control strategies. Honeywell, Inc. has supplied the lighting-control system for the first demonstration, and we have installed it on one floor of the San Francisco PG&E building and are collecting data. The system controls groups of lamps and can dim the lamps over a continuous range of lighting levels. General Electric will supply the control system for the second demonstration, to be carried out in the World Trade Center in New York. This system allows only on-off control, but fixtures can be individually controlled. The second demonstration will start in early 1980. Both contractors have done marketing studies that indicate a large potential market, primarily for new construction. At present, it is not cost-effective to install these control systems in existing buildings because of the block manner in which lighting systems have been wired. However, wiring codes in California require that the periphery light-

Table 2. Comparative performance of circline fluorescent-lamp systems and 100-watt incandescent lamps.

	Commercial products with core-coil ballasts			EETech system with electronic ballasts	Incandescent
Lamp	FC12T10ww	FC6T9ww	FC10T9sw	FC10T9sw	
Power (watt)	35	21	44	44 (19.5)	100 W
Light (lumens)	1226	700	1812	2018 (790)	1750
Efficacy (lumens/watt)	35	33.3	41.2	45.8 (40.5)	17.5

ing of new buildings be independent of the interior lighting, a modification that will substantially reduce the cost of installing automatic control systems.

The demonstration data on the two systems will help in evaluating different control strategies, such as daylighting, group vs. single, continuous vs. step-dimming. For instance, the data will be used to verify the accuracy of a computer program being developed by Smith, Hinchman, and Grylls, under subcontract to LBL, to predict the energy savings that can be realized by using various types of lighting controls, strategies, and maintenance practices.

Daylighting projects related to lighting controls are covered in the Windows section of this report.

Solid-state Ballasts for High-intensity-discharge Lamps

LBL awarded contracts to three firms for developing a solid-state ballast for operating high-intensity-discharge (HID) lamps. Each contractor has been required to deliver six units for testing at the LBL Lighting Laboratory. The preliminary results indicate that high-pressure-sodium (HPS) lamps are 15-20% more efficient when operated at high frequency with solid-state ballasts (combined ballast and lamp efficacy).

Energy-Efficient Light Bulbs

During 1979, we also made preliminary plans for initiating a new project to develop an energy-efficient replacement for the standard incandescent lamp. The project will begin in 1980 with a public competition inviting companies in the lamp-development field (by a Request for Proposal procedure)to elaborate a cost-sharing proposal aimed at achieving accelerated commercialization of an energy-efficient incandescent replacement. The project will have three phases, the first of which should be completed in the latter part of 1980 with the delivery of a pre-manufacturable prototype for testing at LBL. We intend to have several firms working on the problem so that a number of different concepts can be evaluated.

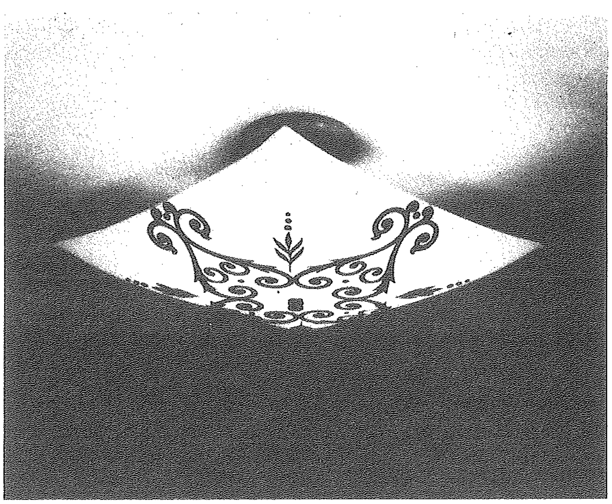

Fig. 1a. Adaptive circline fixture. (CBB 790-15389)

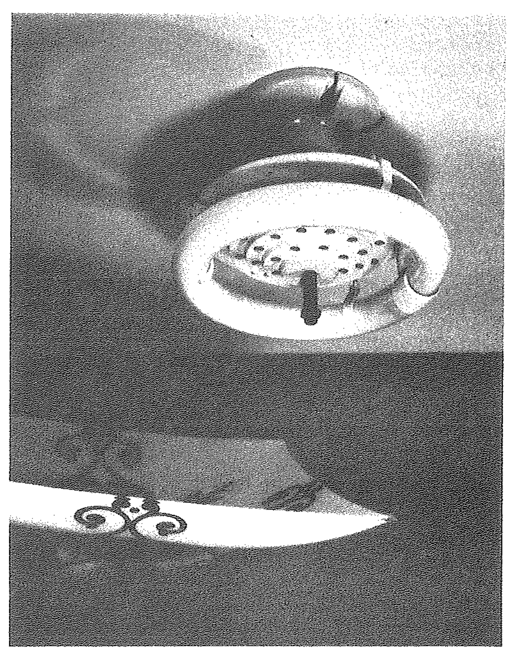

Fig. 1b. Adaptive circline fixture with diffuser. (CBB 790-15387)

PLANNED ACTIVITIES FOR 1980

Besides continuing the above projects, we will begin work in two new program areas: sensors and controls, and visual performance. To study sensors and controls we will set up two new demonstration projects. The sensors project will test the energy that can be saved by introducing a personnel detector that senses room occupancy, turning lights on or off according to the presence or absence of occupants. The demonstration will take place in an office building in New York City; work will be carried out in conjunction with the New York State Energy Research and Development Authority and the Tishman Research Company. The controls demonstration, which will also take place in an office building, will determine the appropriate placement of photodetectors to optimize the performance of control systems in daylit spaces.

The visual-performance program will analyze the theoretical implications of previous research and initiate simple and direct experiments in cooperation with the faculty of the University's School of Optometry. We intend to examine the information requirements that relate energy efficiency in lighting to lighting standards. We will consider the impact of visibility, visual performance, and overall productivity on both the introduction of new lighting technologies and the development of energy-performance standards for the entire building.

CONSERVATION POTENTIALS: COMPILATION, PUBLICATION, AND DEMONSTRATION

A. H. Rosenfeld, H. Arin, M. Maulhard, A. Meier, J. Poling, L. Schipper, L. Wall, and J. Wright

The Building Energy Compilation and Analysis (BECA) Group, initiated in 1976, compiles the results of energy-conservation research performed at LBL and other laboratories worldwide, and publishes comprehensive tables of conservation options, ordered by annual return on investment. We advise utility companies, local governments, and the State of California on conservation options, and promote demonstrations and training in retrofitting.

PUBLISHED REPORTS, DATA BASE AND OTHER ACTIVITIES

Some Potentials for Energy and Peak Power Conservation in California.[1]

In this report, we analyzed known conservation measures for buildings and appliances, and ranked them by cost of conserved energy (in \$/barrel saved). Tables of conservation options were presented in order of maximum return on investment. We calculated that, if these options were implemented over 10 years, the following savings would result: about 30% each in natural gas and electric energy, and nearly 50% in peak power, compared with 1975 consumption. The annual savings to the California consumer would be about \$1 billion in natural gas and \$1 billion in electric bills (at 1975 prices). This saving, if redirected from energy purchases to more typical and labor-intensive purchases, would create about 60,000 jobs in California. Moreover, the \$5 billion initial cost of a 10-year program would be more than offset by a 12 gigawatt reduction in peak-power demand, which would permit deferring the construction of new plants, whose total cost would be about \$10 billion.

In a similar vein, we published Energy Conservation through Appliance Labelling: Facts and Fact Sheets[2] in 1978; Conservation Options in Residential Energy Use[3] in 1977; and Saving Half of California's Energy and Peak Power by Long-range Standards and Other Legislation[4] in 1978. We are now expanding the data base on end-use of energy and conservation options on which these reports were based. New projects are:

Low-Cost/No-Cost Residential Conservation Measures. During 1979, as prices for home heating oil rose toward \$1/gallon, there was revived interest in retrofitting homes and in legislation providing new incentives for home audits and retrofitting. Accordingly, we updated our existing data on California and collected additional data on cities in other parts of the country. Some of this work is reproduced in Fig. 1 and Tables 1 and 2.

BECA: An International Comparison and Critical Review. The Review will consist of three parts, which are to be updated and republished regularly:

Part A: Single-Family Residences

Part B: Retrofitting of Residences

Part C: Commercial Buildings

Part A will be published for the first time in Energy and Buildings in April 1980; it was compiled by eleven researchers from North America and Western Europe.[5] It gives data on the fuel energy used for space heating in single-family residences in the U.S., Canada, and

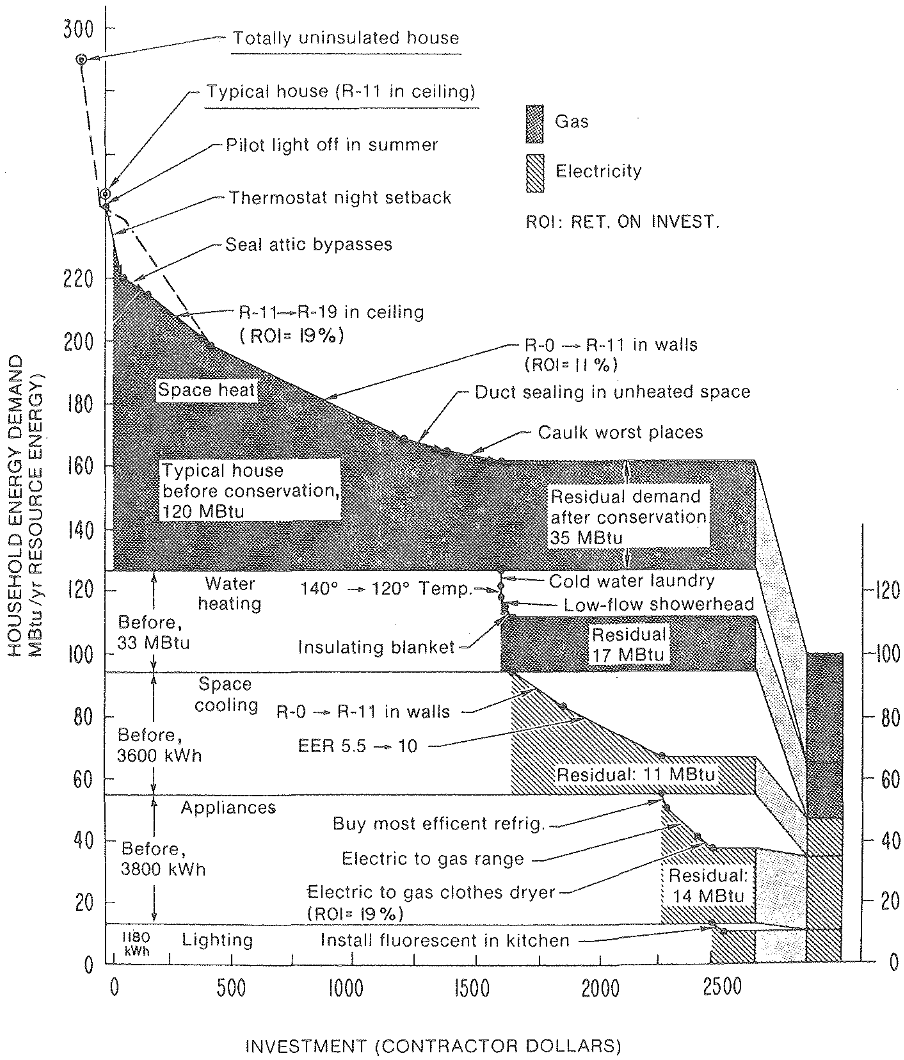

Fig. 1. Conservation potential for a Northern California single family home (1200 ft.^{2}, 3000 heating degree days). From Maulhardt, Meier, Newbold, Rosenfeld, and Wright, LBL-5926 (rev. 11/79), Lawrence Berkeley Laboratory, Berkeley, CA. (XBL 7910-13101)

Western Europe. Three classes of data are plotted and compared: (1) calculated data determined by computer simulation or by simplified calculation, (2) housing-stock data obtained from gross consumption figures in given countries for a given year, and (3) measured data for individual dwellings built as (or modified into) energy-efficient houses. The computer simulations calculate the energy used to heat a residence constructed according to current building codes or practice. A description of optimum construction, based on minimum life-cycle cost, is given for the U.S., and data on the cost of moving from one construction level to another are provided. The combined results on actual houses show the low annual fuel requirements for space heating that can be achieved in new houses and by retrofitting existing ones. In most existing houses, the space-heating requirements can be reduced by about 50% with an investment of $1,500. In new houses, a reduction of more than 60% can be achieved by investing $1,500 in improvements over and above those called for in current practice.

Topics covered briefly in Part A are: other energy-conservation designs such as passive solar heating and insulating shutters or shades; and indoor air quality in tight houses, including radon concentrations.

Figures 2, 3, and 4 are from BECA, Part A.

Storage of Heat and Coolth in Hollow-Core Concrete Slabs. Swedish Experience, and Application to Large, American-Style Buildings.[6] We have collaborated with a team of Swedish researchers to produce a report on the storage of heat and "coolth" in hollow-core concrete slabs. We analyzed the Folksam office building in Farsta, near Stockholm, which has been functional since December 1977, with an energy use for direct space heating of only 60 kWh/m^2 (19,000 Btu/ft^2), half the Stockholm average for

Table 1. Lo-cost/no cost residential conservation measures - Northern California (Travis AFB).

We assume a 1200 square foot house, with R-11 in the attic, and no night thermostat setback in a climate of 2400 heating degree days and 1200 cooling degree days. Before retrofit, the house used 1200 therms (or 21,200 kWh) for space heating, 3600 kWh for air conditioning, 330 therms (or 5000 kWh) for water heating and 1200 kWh for refrigeration. The seasonal efficiency of the furnace/duct system before retrofit was taken as 60%.

Measure	Alternative Costs: By Contractor	By Homeowner: Deluxe	By Homeowner: Simple	Annual Savings: Electric kWh	Electric @5c/kWh	Natural Gas Therms	Natural Gas @30c/Th
1. Low Temperature Laundry							
warm wash/cold rinse or	$0	$0	$0	600	$30	35	$11
(all cold water)	($0)	($0)	($0)	(1000)	($50)	(50)	($15)
2. Reduce Hot Water Temperature							
140 deg. to 120 deg. or	$0	$0	$0	350	$17	25	$8
(140 deg. to 110 deg.)	($0)	($0)	($0)	(520)	($26)	(35)	($11)
3. Shower Flow Restrictors	$20[a]	$8	$1	750	$38	35	$11
4. Blanket on Water Heater	$30[a]	$20	$5	350	$18	24	$7
5. Other Turnoffs							
a. Furn. Pilot Off in Summer	$0	$0	$0	-	-	35	$11
b. Refrig. Anti-Sweat Switch	$0	$0	$0	120[b,c]	$6	-	-
c. Second Refrigerator	$0	$0	$0	900[b,c]	$45	-	-
6. Heating and Cooling Systems							
a. Set Back Furnace Fan Thermostat	$15[a]	$5	$0	-	-	30	$9
b. Night Thermostat Setback to 60 deg.	$75[a]	$60	$0	4100	$200	230	$70
7. Plug Fireplace Flue	$35	$15	$5	230	$11	15	$5
8. Seal Air Bypass Paths to Attic	$100[a]	$40	$10	750	$37	35	$11
9. Seal and Insulate Ducts in Unheated Areas	$175	$50	$25	550	$28	30	$10
10. Caulk and Seal Build. Shell	$220	$60	$15				
Heating				620	$31	35	$11
Cooling				200[c]	$10	-	-
TOTALS (see note c)	$670	$260	$60	1200[c] (25%)	$60[c]	530[c] (35%)	$160[c]

a. assumes the measure was part of a contractor package job.

b. not included in total because original requirements did not include appliances.

c. For total savings, to avoid double counting, we assume gas used for space and water heating, electricity for cooling and refrigeration (where the gas columns show a dash).

2-z setback
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new buildings. To this amount must be added another 60 kWh/m^2 for lights, equipment, fans, etc. New Swedish buildings are so well insulated that their temperature rises during winter working days. In the Folksam building, the surplus heat from the 40 hours per week that the building is occupied is stored in hollow-core concrete slabs and then used to compensate for the heat losses during the 128 remaining hours. The energy transport and storage system necessary to keep the indoor temperature comfortable, summer and winter, is called Thermodeck; it is described in detail in the report.

Fig. 5, taken from the report, shows how the Thermodeck system can also eliminate the need for daytime air conditioning.

California Policy Seminar

We received a grant from the California Policy Seminar to update the report on potentials for conserving energy and peak power in California[1] and to consider further savings that might be realized if long-range standards for buildings and appliances were adopted. We are also computerizing our data base and writing several policy papers under this grant.

Energy "Points" for Real-Estate Appraisers

In a project related to our Low-Cost Residential Conservation Measures, we are calculating the energy savings of applying residential conservation options in ten cities. The results will be listed as points on a form intended for use by real-estate appraisers.

Retrofitting Projects

In collaboration with Princeton University, we have developed the practice of partially retrofitting a residence as it is being audited in accordance with the Residential Conservation Service legislation. If we assume a situation in which gas or oil use in a partially retrofitted house is reduced by 25%, then a homeowner who spends $250 on the retrofitting procedures can save $100/year in energy costs, which works out to 25¢/MBtu or $1.50/barrel.

Table 2. Lo-cost/no cost residential conservation measures - Chicago/Boston

We assume a 1200 ft.^{2} house, with R-11 insulation in the ceiling, R-7 in the walls, no night thermostat setback, and 6000 heating degree-days per year. Before retrofit the house used 2200 therms (32,000 kWh or 1570 gal. of oil) for space heating and 300 therms (or 5000 kWh) for hot water. Air conditioning in Chicago uses 2300 kWh, but we do not consider a/c savings. Gas and oil seasonal furnace/duct system efficiency before retrofit was taken to be 50 percent.

Measure	Alternative Cost			Annual Savings					
	Work By Contr.	By Homeowner Deluxe	By Homeowner Cheap	Electric kWh	Electric @5¢/kWh	Natural Gas Therms	Natural Gas @37¢/Th	Oil gal	Oil @85¢/gal
1. Low Temperature Laundry									
warm wash/cold rinse, or	$0	$0	$0	600	$30	50	$19	-	-
(all cold water)	$0	($0)	($0)	(1000)	($30)	(55)	($20)	-	-
2. Reduce Hot Water Temp.									
140 deg. to 120 deg. or	$0	$0	$0	350	$17	25	$9	-	-
(140 deg. to 110 deg.)	$0	($0)	($0)	(520)	(26)	(35)	($13)	-	-
3. Shower Flow Restrictor	$20[a]	$8	$1	750	$38	35	$13	-	-
4. Blanket on Water Heater	$30[a]	$20	$5	350	$18	24	$9	-	-
5. Other Turnoffs									
a. Furn. Pilot Off In Summer	$0	$0	$0	-	-	30	$11	-	-
b. Refrig. Anti-Sweat Switch	$0	$0	$0	120[b]	$6	-	-	-	-
c. Eliminate Second Refrig.	$0	$0	$0	900[b]	$45	-	-	-	-
6. Heating and Cooling Systems									
a. Set back Furn. Fan T'stat	$15[a]	$5	$0	-	-	30	$11	21	$18
b. Night Thermostat Setback to 60 deg.	$75[a]	$60	$0	5500	275	320	$120	230	$194
c. Furnace Tuneup	$35[a]	-	-	-	-	220	$81	157	$133
7. Plug Fireplace Flue	$35	$15	$5	900	$45	60	$22	43	$37
8. Seal Bypass Paths To Attic	$100[a]	$40	$10	1400	$70	80	$30	57	$48
9. Seal And Insulate Ducts In Unheated Areas	$175	$50	$25	1900	$95	130	$48	93	$79
10. Caulk And Seal Building Shell, Worst Places Only	$220	$60	$15	1500	$75	100	$37	71	$60
TOTALS (see note d)	$700	$260	$60			1100 (44%)	$410	670[d] (43%)	$570[d]

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a. assumes measure was part of a contractor package job.

b. Not included in total because original requirements did not include appliances.

d. Oil savings apply for space heating alone; domestic water heated by gas.

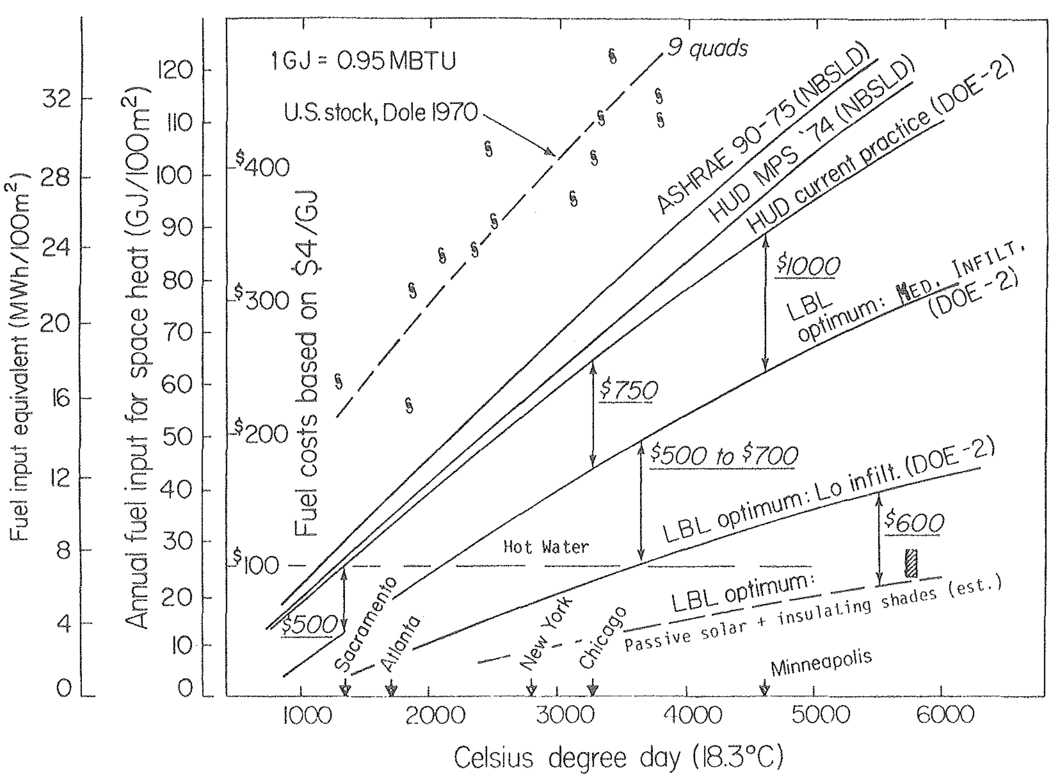

Fig. 2. U.S., fuel for single-family residential space heating. (XBL 795-1396A)

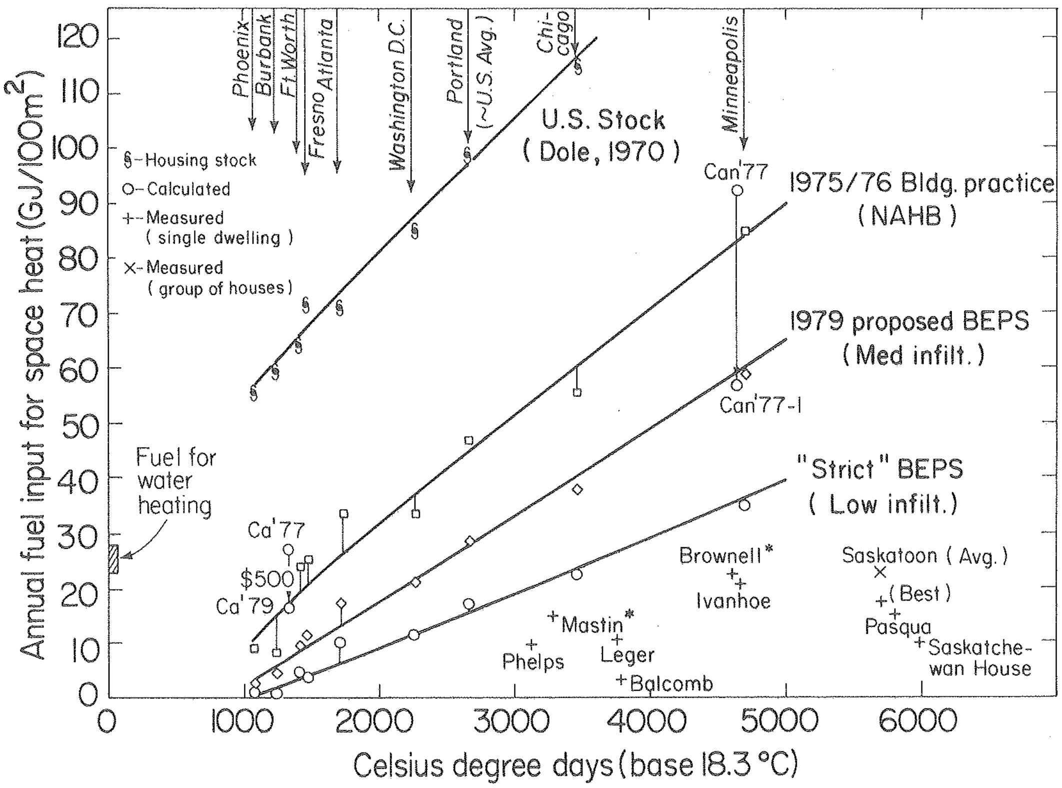

Fig. 3. North America, fuel for single-family residential space heating. (XBL 807-1680)

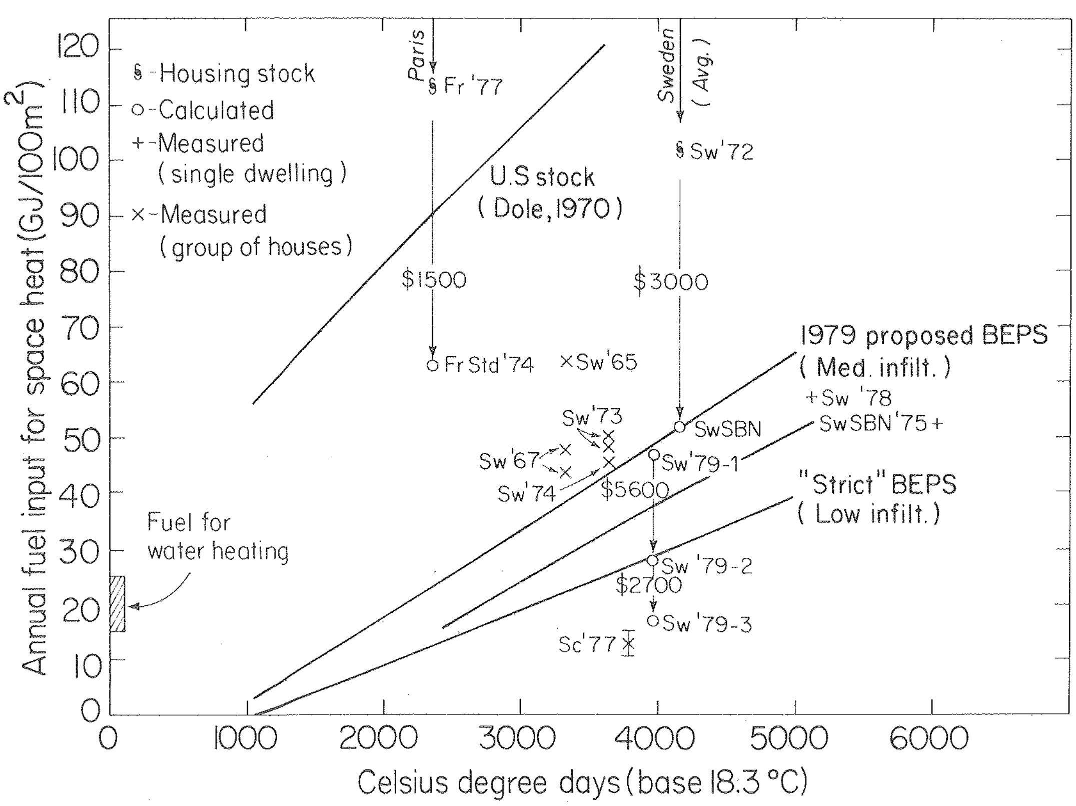

Fig. 4. Europe, fuel for single-family residential space heating. (XBL 807-1679)

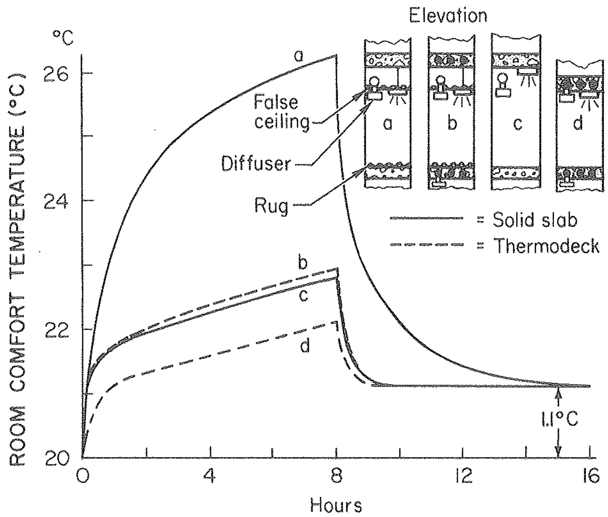

Fig. 5. Response/relaxation curves calculated by the BRIS-program for equal rooms with two different slabs, each with a heat capacity of 100 Wh/m^2K. The surroundings are assumed symmetric on all sides (as in an office in the core of a building). 15 W/m^2 of lighting (50% radiation) is turned on for the first eight hours of each run. The cases are as follows:

a. 20-cm thick solid concrete slab, with rug, insulated, suspended ceiling, and plenum. Resistances assumed were: rug -- 0.1 $(W/m^2K)^{-1}$; insulated false ceiling -- 0.5; plenum -- 0.17.
b. Same as a., but slab is 30-cm thick Thermodeck.
c. 20-cm thick concrete slab, but bare -- no rugs, suspended ceilings, plenum.
d. Same as c., but slab is 30-cm thick Thermodeck.

(XBL 7910-13104)

To test and demonstrate the economics of retrofitting, we are working with the Pacific Gas and Electric Company to partially retrofit 20 homes in Walnut Creek, California, and then to fully retrofit six of them. This activity is part of a broader program, covering 150 homes, that has been organized by Princeton University.

Also with Princeton, we are proposing to carry out a demonstration project in which 1,000 homes would be retrofitted. The project would also be used to train "house doctors" (persons skilled in diagnosing sources of energy waste in a house) and to give utility company personnel experience in conducting audits and in partially and extensively retrofitting homes.

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SUMMARY AND DISCUSSION OF POTENTIAL SAVINGS IN THE BUILDINGS SECTOR

A. H. Rosenfeld

OVERVIEW

In 1979 the U.S. consumed about 79 quadrillion Btu's of resource energy (1 quad per year = 1/2 million barrels of oil per day). Because automobiles are so visible, many Americans first think of energy consumption in terms of gasoline used to fuel cars; in fact, gasoline use was only 14 quads. The next highest energy consumer in the minds of the public is industry, and, at the bottom of the list, our homes and workplaces. To the surprise of most, our homes and workplaces in 1979 used as much energy as industry -- 29 quads each.

Table 1 shows a breakdown of energy consumption by sector (residential, commercial, industrial, transportation) and by supply (fossil

Table 1. Comparative energy consumption by sector and resource (United States, 1977)

	Resource Energy (Quads)					
	Fossil Fuel		Electricity		Total	
Buildings:						
• Residential	10	(3)*	7	(3)	17	(6)
• Commercial	4	(1)	7	(2)	11	(3)
All Buildings	14	(4)	14	(5)	28	(9)
Industry	21	(21)	8	(8)	29	(29)
Transportation:						
• Gasoline	14	(7)	---	---	14	(7)
• Other	7	(7)	---	---	7	(7)
All Transportation	21	(14)	---	---	21	14
TOTAL	56	(39)	22	(13)	78	(52)

*Figures in parentheses represent estimated energy use if all homes, buildings and appliances were replaced with new ones, optimized to minimize life-cycle energy cost, and autos meet the 1985 standard of 27.5 mpg.

fuel vs. electricity) for 1977. Note that residences alone use more energy than motor cars, and that buildings and appliances use 60% of our electricity. Figures in parentheses reflect our estimate of energy consumption if all homes and buildings were magically retrofitted or replaced with new ones whose energy use has been optimized to minimize life-cycle energy costs, and if automobiles were brought up to 1985 fuel-economy standards. Based upon our projections, we estimate potential energy savings of 19 quads in the building sector and 7 quads in the transportation sector. The result is that the 29 quads used by the buildings sector would drop to 9, and the 21 quads used for transportation would drop to 14.

RETROFITTING

Although it would take 50-100 years to replace all our homes and buildings, that somber fact does not mean that national energy conservation is a utopian prospect. Results of our research on retrofitting existing buildings suggest that energy requirements for space heating can be reduced by 50% (14 quads to 7) and electricity by approximately 35% (14 quads to 10). It is this potential supply of "conserved energy" (11 quads) that gives rise to articles with such exuberant titles as "Drilling for Oil and Gas in our Buildings."[1] By comparison, it is instructive to look at the National Energy Plan that would invest $88 billion in plants to produce annually 5 quads of synthetic fuel and unconventional oil and gas. To this $88 billion must be added a continuing annual cost of primary fuel inputted to the synfuel plant. Retrofitting existing buildings, on the other hand, will save 11 quads of energy for a gross capital investment of $140 billion, or, if federally-financed, an annual carrying cost of approximately $16 billion. In other words, such a national conservation program, for a smaller one-time initial investment, could produce twice what the synfuel program is projected to produce — not only at less cost but with a shorter payback time, some immediate benefits, and a higher probability of minimizing U.S. dependence on foreign energy sources in the near future.

Figure 1 of the article on "Conservation Potentials" in this chapter shows 20 steps designed to reduce existing energy use in a typical Northern California house by 60%, thus saving 140 MBtu/year. Assuming an average retrofit life of twenty years and an investment of $2,500 to accomplish these retrofits, then at a 10% discount rate the 140 MBtu/year saving would cost $294/year. The "conserved energy" cost is thus $\frac{\$294}{140\text{MBtu}}$ = $2.10/MBtu, or $12.18/barrel.

REDUCING INFILTRATION

The most novel and cost-effective retrofit measure is to reduce natural infiltration of outside air. In the typical U.S. house which contains 80 lb. of air, infiltration averages 1 ach (air changes per hour). In winter, this incoming outside air must be heated hourly, and in summer the air must be cooled and dried in regions where air conditioning exists.

To heat all infiltrating air in a typical Boston house for one heating season adds to the normal heating load the energy and costs tabulated below:

Heating System	Furnace Efficiency	Fuel	Unit Price	Annual Heating Bill
Natural Gas	60%	450 therm	40¢/ea.	$180
Oil	60%	340 gal	$1/gal	$340
Electric Resistance	100%	13,000 kWh	5¢/kWh	$650

A good job of air-tightening this house could reduce infiltration by 25% to 50% and save a corresponding amount of energy and dollars.

Increased energy prices have encouraged builders to tighten construction in new houses where, on the average, infiltration has been reduced to about 0.6 ach. There are even examples of energy-efficient houses which have been built with 0.1 - 0.2 ach; however, when infiltration is reduced, indoor pollutants such as odors, moisture, formaldehyde, radon gas, and combustion products from cooking with a gas stove, all build up, and indoor air quality becomes unacceptable. One promising solution is to install a fan to supply fresh air and exhaust stale air through an air-to-air heat exchanger. The EEB program is addressing this problem (see Ventilation Program).

NEW BUILDINGS

In addition to exploring retrofit possibilities in existing houses, the EEB program is concerned with new energy-efficient designs in buildings. Indeed, the various research programs described in this chapter have the common aim of providing baseline data needed to establish building energy performance standards (BEPS) which Congress has mandated for 1980. The BEPS program is discussed in detail in the following article. Figs. 2 and 3 in "Conservation Potentials" show some of the improvements to be included in building standards for single-family housing stock in various geographical locations, and the energy savings that can be achieved by incorporating these energy-conserving features. For a typical house in Chicago, space heating requirements (gas) can be reduced by 85% (from 65 MBtu = $260 to 10 MBtu = $40) by using better windows, adding insulation, reducing infiltration, installing heat exchangers, and utilizing solar gain.

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EVALUATION OF BUILDING ENERGY PERFORMANCE STANDARDS FOR RESIDENTIAL BUILDINGS

M. Levine, D. Goldstein, M. Lokmanhekim, J. Mass, and A. Rosenfeld

INTRODUCTION

In August of 1976, in response to the need for encouraging greater conservation of depletable energy resources in new buildings, Congress passed the Energy Conservation Standards for New Buildings Act of 1976. The Act mandated the development, promulgation, implementation, and administration of energy performance standards for all new buildings constructed in the United States after 1981.

The importance of the Building Energy Performance Standards (BEPS) program in the residential sector is underscored by results showing that setting the residential standard at the minimum in life-cycle costs using only traditional energy conservation measures can:

- reduce energy use for space conditioning by about 30% - 40% from current building practice (or 60% - 70% from an average house built before the OPEC oil embargo of 1973)
- produce a net savings in life-cycle costs of more than $1,000 to an average new homeowner.

Lawrence Berkeley Laboratory (LBL) was assigned primary responsibility for the support of the U.S. Department of Energy's (DOE's) development of the energy performance standards for single-family residential buildings in December, 1978. During Fiscal Year 1979, LBl completed the following tasks in support of the standards development:

1. Development of prototype designs for single-family residential buildings;
2. Description of conservation measures and building operating conditions for residential dwellings;
3. Building energy simulations using a state-of-the-art energy analysis computer program (DOE-2) of four buildings in ten locations with approximately twelve combinations of energy conservation measures for each building;
4. Development and application of a computer program to evaluate the life-cycle costs of the conservation measures in the residential buildings;
5. Analysis of the sensitivity of the life-cycle cost curves to variations or uncertainties in key economic parameters and building and climate characteristics;
6. Preparation of a series of memos and issued papers on the key policy issues resulting from the analysis of residential Building Energy Performance Standards (BEPS); and

7. Active participation with DOE in the preparation of the Notice of Proposed Rulemaking for the BEPS.[1]

The LBL research effort during Fiscal Year 1980 will focus on: (1) key issues that need to be resolved for the final rulemaking; (2) planning of a research effort to increase the energy conservation potential in residential buildings, in support of an update of the standards anticipated in 1985; (3) initiation of selected research tasks treating advanced energy conservation technologies (discussed in an article in this volume by D. B. Goldstein, J. Mass, and M. D. Levine); (4) support for DOE in its efforts on commercial buildings and mobile homes; and (5) participation in DOE's public information program on BEPS.

METHOD OF APPROACH

The approach followed in the analysis of residential space conditioning energy performance standards involves the following steps:

1. Development or residential prototypes,
2. Selection of conservation measures to be evaluated,
3. Description of standard building operating conditions,
4. Development of economic data, projections, and assumptions,
5. Computer simulation of building energy requirements in different climatic regions,
6. Analysis of life-cycle costs of energy conservation measures,
7. Sensitivity analyses on building characteristics, operating conditions, conservation measures, and economic parameters, and
8. Analysis of impacts of alternative energy budget levels, in which the alternative budget levels are based on steps 1 through 7.

The basis of the analysis method is the use of life-cycle costing. The objective of achieving a minimum in life-cycle costs is a reasonable basis for establishing energy conservation policy because it provides a rational framework for trading off scarce energy resources and other resources (e.g., labor and capital) in achieving a particular goal (in this case, space conditioning in residential buildings).[2] The use of an economic approach to energy conservation--and the increasing public awareness of how economics can help resolve issues--can be greatly enhanced by a government decision to use life-cycle costing as one of the major elements of its energy conservation policy.

Specifics of Approach and Assumptions

The most important specific elements of the approach to evaluating the life-cycle cost of energy conservation measures for single-family residential buildings are summarized below. More detailed information on the assumptions used in the analysis is found in Ref. 3. More detailed information about the results of sensitivity analyses is found in Chapter 4 and appendices A and I of Ref. 4.

Residential Prototypes

- Four designs selected, following Hastings:[5] single story ranch, two story, townhouse, and split level house.
- Window area taken to be 15% of floor area for all designs.
- Windows equally distributed on all four sides of house (two sides for townhouse).
- Sensitivities of prototypes performed:

  --window area
  --window orientation
  --house size and orientation
  --aspect ratio of house
  --thermal mass of house
  --conservation measures (see below)
  --building operating conditions (see below)

Conservation Measures

- Windows: up to triple glazing (or double glazing plus storm window).
- Exterior wall: up to R-25 (using 2" x 6" studs plus insulating sheathing).
- Ceiling: up to R-38 insulation.
- Excludes: exterior wall with double studs (two 2 x 4 or 2 x 8 studs with insulation); ceiling insulation greater than R-38; infiltration reduction (with or without heat recuperator); any conservation measure requiring a change in behavior; other advanced energy conservation technologies.

Building Operating Conditions

- Thermostat set points: 70°F for heating; 78° for cooling; no night setback.
- Average air infiltration rate: 0.6 air changes per hour.
- Average internal loads: 50,000 Btu/day, Highest in early morning (cooking, occupants, lighting) and evenings (cooking, lighting, occupants, TV).
- Natural ventilation: windows open when indoor temperature greater than 78°F and outdoor temperature low enough to cool house to 78° in less than one hour. Non-opening windows considered as a sensitivity case.

Economic Data, Projections, and Assumptions

- E.I.A. average energy price projections

(Series B)

--Gas prices escalate at 2.8% per year above inflation,
--Electricity prices escalate at 1.5% per year above inflation.

- Installed cost of energy conservation measures from N.A.H.B.

- Discount rate chosen to equal cost of borrowed capital for a new house (3% above inflation).

- Possible future changes in assumptions:

--marginal energy prices
--updated conservation costs
--regional prices

Building Energy Simulations

- Use of DOE-2 computer program, checked against TWOZONE and BLAST.

- Change in infiltration and ventilation algorithms.

- Run for 4 prototypes, about 12 groups of conservation measures per prototype, two ventilation algorithms and 10 cities.

RESULTS

Gas Heated Houses

Table 1 contains the detailed results obtained by minimizing the life-cycle costs of energy conservation investment and a discounted stream of payments for fuel over the lifetime of the house mortgage, for a house with natural gas heating (assuming a system efficiency of 70 percent) and electric cooling. The first column lists the climatic regions. The second column presents the representative city for which the thermal analysis of the residence was performed. Columns 3 and 4 show the long-term average heating and cooling degree days for each of the cities. The heating degree days are presented with a base of 65°F and, in parentheses, a base of 53°F. The cooling degree days are presented with a base of 65°F and, in parentheses, a base of 68°F. (The 53°F base for heating and 68°F for cooling are included because space heating and cooling loads for a well-insulated house are expected to be more nearly linear with degree days calculated on this basis than for the traditional base of 65°F.)

Column 5 presents the insulation levels and column 6 the number of glazings in the prototype house which minimized life-cycle costs.* These insulation levels would bring most houses into compliance with the energy budgets. Of course, many other configurations would also comply. Triple glazing is used in climates as cold as Washington, D.C., and in areas with very large cooling load, and double glazing is used in all other climates modeled. Typical insulation levels for all but the extreme climates (coldest or mildest) are R-38 ceiling and R-19 walls. Column 7 contains the estimated increase in investment (for an 1176 square foot house) for the conservation measures compared with current investment in conservation in the different climates. (The estimates of current conservation investment are based on a NAHB survey, results of which are contained in Table 2.[6]) Column 8 contains the energy budget at the life-cycle cost minimum, which we have previously defined as the Design Energy Budget of a house. We have expressed these budgets in terms of primary energy use and use at the building boundary.

There are numerous ways that the Design Energy Budgets can be met in the different climates. Table 3, taken from Refs. 1 and 7, illustrates two or three alternative ways of achieving the Design Energy Budgets in three climates.

Electric Resistance Heated Houses

Table 4 summarizes the life-cycle costing results for electric resistance heating. Columns 5 and 6 show the standard insulation and glazing levels that will meet the designed energy budgets of the nominal case: R-38 ceiling and triple glazing insulation is used in all climates except the most mild (Burbank); R-25 wall insulation is used in all climates as cold as or colder than Washington, D. C. and R-19 wall insulation in all other climates. Thus, in all climates except region 1 (Minneapolis), the standard conservation

*For regions in which a crawl space is the common form of basement, the floor insulation levels are noted in Table 1. For unheated full basements, the assumption is made that heat losses and gains balance. Slab on grade and basement construction is assumed to have adequate perimeter insulation, as described in Ref. 1.

Table 2. Standard energy conservation measures for residential houses constructed in 1975, based on data from the 1977 NAHB survey.

	Standard Practice, 1975			
City	C	W	F	Gl[a]
Minneapolis	22	11	--	2
Chicago	19	11	--	2
Portland	19	11	7	2
Washington, D.C.	19	11	--	2
Atlanta	19	11	7	1
Fresno	19	11	--	1
Burbank	19	11	--	1
Phoenix	19	11	--	1
Houston	19	11	--	1
Ft. Worth	19	11	--	1

[a] C = ceiling R-value; W = wall R-value;
F = floor R-value (if applicable);
Gl = number of glazings for all windows.

Table 1. Results of the life-cycle cost analysis of energy conservation measures for single story houses heated by natural gas and cooled by electricity.

1	2	3	4	5			6	7	8	
				Insulation Levels of Nominal Case (R-Value)					Natural Gas Energy Budget	
Climate Region	Representative City	Heating Degree-Days[a]	Cooling Degree-Days[a]	Ceiling	Wall	Floor	Glazing of Nominal Case	Conservation Investment, $1978	Primary Energy, MBtu/sq. ft./yr	Building Boundary, MBtu/sq. ft./yr
1	Minneapolis	8310 (5260)	530 (370)	38	25	--	3	$1,160	66.1	54.5
2	Chicago	6130 (3540)	930 (620)	38	19	--	3	$ 900	42.9	35.0
3	Portland	4790 (1840)	300 (150)	38	19	19	3	$1,050	30.9	25.9
3	Washington, D.C.	4210 (1980)	1420 (1010)	38	19	--	3	$ 900	33.7	22.4
4	Atlanta	3100 (1230)	1590 (1130)	38	19	11	2	$ 900	28.2	18.3
4	Fresno	2650 (770)	1670 (1220)	38	19	--	2	$ 850	31.9	16.1
5	Burbank	1820 (170)[b]	620 (310)[b]	19	11	--	2	$ 380	15.7	7.2
6	Phoenix[c]	1550 (320)	3510 (2960)	38	19	--	3	$1,280	35.8	12.0
6	Houston	1430 (360)	2890 (2240)	30	11	--	2	$ 520	34.4	15.1
7	Ft. Worth[c]	2830 (810)	2590 (2030)	38	19	--	3	$1,280	32.3	15.2

[a]Heating and cooling degree-days base 65°F presented; heating degree-days base 53°F in parentheses; cooling degree-days base 68°F in parentheses.
[b]Degree-days for Los Angeles reported.
[c]Under the EIA Medium Price Projections (December 17, 1978) both Phoenix and Ft. Worth would have used double glazing at a conservation investment of $850. Primary energy use was 40.1 and 36.8 MBtu/sq. ft./yr for Phoenix and Ft. Worth, respectively.

Table 3. Illustrative ways of meeting the design energy budgets for single family residences in three locations: gas heated homes.

Location	Sets of Options
Chicago, IL	1. Average window area and distribution;[a] triple glazing;[b] R-38 ceiling and R-19 wall insulation.
	2. Windows redistributed so that south facing window area increased by 75% and east, west, and north facing window area decreased by 25%; double glazing; R-38 ceiling and R-9 wall insulation.
	3. Active solar domestic water heating system;[d] double glazing; R-38 ceiling and R-11 wall insulation.
Atlanta, GA	1. Average window area and distribution;[a] double glazing; R-38 ceiling, R-19 wall, and R-11 floor[c] insulation.
	2. Windows redistributed so that south facing window area increased by 75% and east, west and north facing window area decreased by 25%; double glazing; R-30 ceiling, R-11 wall and R-11 floor insulation.
	3. Active solar domestic water heating system;[d] double glazing; R-19 ceiling, R-11 wall and R-7 floor insulation.
Houston, TX	1. Average window area and distribution;[a] double glazing; R-30 ceiling and R-11 wall insulation.
	2. Active solar domestic water heating;[d] R-19 ceiling and R-11 wall insulataon.
	3. Other alternatives, such as passive solar design and redistribution of windows, not evaluated for Houston.

[a]The average window area is 15% of total floor area. The windows are distributed equally among the exterior walls.

[b]Double glazing plus storm windows can substitute for triple glazing with little change in the Design Energy Consumption of the house.

[c]Floor insulation is noted in Atlanta, Georgia, and all other areas where crawl-space basements are used.

[d]The active solar domestic water heating is assumed to be sized at 60% of the water heating load in a 1500 square foot house for the purpose of this illustration.

Table 4. Results of the life-cycle cost analysis of energy conservation measures for single story houses heated and cooled by electric heating (other than heat pumps).

1	2	3	4	5			6	7	8	
				Insulation Levels of Nominal Case (R-Value)					Electrical Energy Budget	
Climate Region	Representative City	Heating Degree-Days[a]	Cooling Degree-Days[a]	Ceiling	Wall	Floor	Glazing of Nominal Case	Conservation Investment, $1978	Primary Energy, MBtu/sq. ft./yr	Building Boundary, MBtu/sq. ft./yr
1	Minneapolis	8310 (5260)	530 (370)	38	25	--	3	$1,160	132.2	38.9
2	Chicago	6130 (3540)	930 (620)	38	25	--	3	$1,190	80.0	23.5
3	Portland	4790 (1840)	300 (1010)	38	25	19	3	$1,350	58.5	17.2
3	Washington, D.C.	4210 (1980)	1420 (1010)	38	25	--	3	$1,190	53.7	15.8
4	Atlanta[c]	3100 (1230)	1590 (1130)	38	19	19	3	$1,433	39.6	11.6
4	Fresno	2650 (770)	1670 (1220)	38	19	--	3	$1,280	38.6	11.4
5	Burbank	1820 (170)[b]	620 (310)[b]	30	19	--	2	$ 760	15.1	4.4
6	Phoenix	1550 (320)	3510 (2960)	38	19	--	3	$1,280	38.5	11.3
6	Houston	1430 (360)	2890 (2240)	38	19	--	3	$1,280	33.6	9.9
7	Ft. Worth	2830 (810)	2590 (2030)	38	19	--	3	$1,280	43.0	12.6

[a]Heating and cooling degree-days base 65°F presented; heating degree-days base 53°F in parentheses; cooling degree-days base 68°F in parentheses.

[b]Degree-days for Los Angeles reported.

[c]Under the EIA Medium Price Projections (December 17, 1978) Atlanta used R-11 floor insulation for a conservation investment cost of $1,330 and a primary energy budget of 40.7 MBtu/sq. ft./yr.

measures for houses using electric resistance heating are stricter than those for natural gas-heated houses. The investment in energy conservation for the electric resistance heated houses reflects the use of tighter measures for all climates except Minneapolis. The increased investment in energy conservation (beyond estimated 1975 current practice) is between \$1,160 and \$1,433 for the 1176-ft^2 wood frame prototype house.

Houses Heated and Cooled with Heat Pumps

Table 5 summarized the life-cycle costing results for heating and cooling with an electric heat pump. Column 8 in Table 5 presents the seasonal coefficients of performance (COP) of heat pumps in the heating mode in ten climates. These COPs are based on the simulation of available efficient heat pumps in ten climates by the Oak Ridge National Laboratory.[8] The COP for a heat pump is reported as 10% lower than can presently be achieved by commercial models to account for heat losses in the ductwork associated with the heat pump.

Comparison of the Design Energy Budgets for the electric heat pump (column 9 in Table 5) with electric resistance heating (column 8 in Table 4) reveals that the heat pump budget is lower than the electric resistance budget in almost all cases. The heat pump budget is significantly lower in cool and cold climates. An economic evaluation of electric heating using heat pumps and using resistance heating indicates that the heat pump system has lower life-cycle costs than resistance heating in cool and cold climates, in spite of the higher first costs of the heat pump.[9]

Table 6 illustrates alternative ways of meeting the Design Energy Budgets that were obtained for homes heated and cooled by heat pumps in three climates.[1,7]

Comparison with Current and Past Energy Conservation Construction Practice

Figure 1 presents a comparison of fuel requirements for space heating using natural gas for a large number of different cases. The upper curve, labeled "U.S. stock, Dole 1970," is the best available estimate of the fuel requirements for space heating the 1970 stock of houses in the United States.[10] The fourth curve from the top labeled "Current Practice (DOE-2)," is our best estimate of the current construction practice in houses built after the 1973 oil embargo. This curve is based on survey data for the years 1975 and 1977 and on results of DOE-2[11] computer calculations performed at LBL.[4] The fifth curve from the top, labeled "LBL optimum medium infiltration," contains the results of life-cycle costing analysis for gas heated houses. The sixth curve, labeled "LBL optimum: low infiltration (DOE-2)," illustrates the energy requirements for a house with infiltration levels reduced from 0.6 to 0.2 air changes per hour. For this case the assumption is made that mechanical ventilation through a heat recuperator restores the outside air exchange rate to 0.6 air changes per hour.

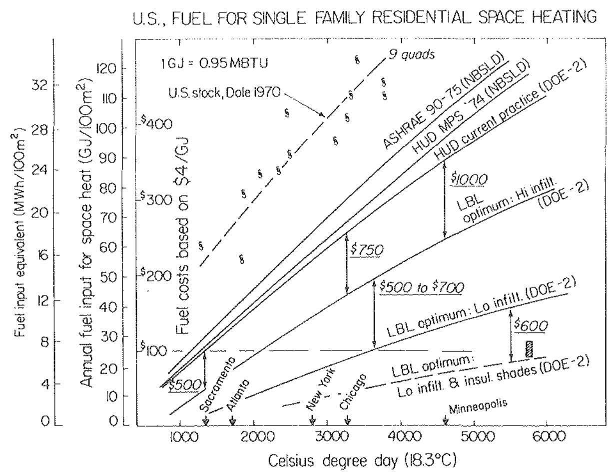

Fig. 1. Fuel for single family residential space heating (U.S.). (XBL 795-1396)

CONCLUSIONS

Figure 1 indicates that very large energy savings can be accomplished by requiring all new houses to use all commonly available cost effective energy conservation measures. BEPS can result in a substantial improvement in the thermal integrity of new houses in the United States and at the same time save the consumer money. The magnitude of the energy savings is sufficiently great as to go a long way toward reducing growth in energy demand in the Nation. (About 35% of energy in the Nation is consumed in buildings with about half of this amount consumed in residential buildings.)

If BEPS is set at the minimum in the life-cycle cost curves (as proposed in DOE's NOPR)[1] and if all new residential buildings meet BEPS then:

- a reduction of 30% to 40% in the average energy use for residential space conditioning (from current building practice) is accomplished. This is a reduction of 60% to 70% from the energy use of an average existing house, built before the OPEC oil embargo in 1973.

- simple payback on conservation investment occurs in 1 to 4 years for electric heat and 3 to 10 years for gas heat;

- an increased investment of \$0.50 to \$1.00 per square foot for a new house is required (i.e., an increased initial investment of 1.5% to 3%); and

- the new home owner achieves a net savings of \$800 to \$1500 over the life of the house mortgage, in addition to a higher selling price of the house.

If the list of conservation measures is expanded to include just one conservation technology (reduced air infiltration combined with mechanical

Table 5. Results of the life-cycle cost analysis of energy conservation measures for single story houses heated and cooled by electric heat pumps.

1	2	3	4	5			6	7	8	9	
				Insulation Levels of Nominal Case (R-Value)						Electrical Energy Budget	
Climate Region	Representative City	Heating Degree-Days[a]	Cooling Degree-Days[a]	Ceiling	Wall	Floor	Glazing of Nominal Case	Conservation Investment, $1978	Heat Pump Seasonal COP	Primary Energy, MBtu/sq. ft./yr	Building Boundary, MBtu/sq. ft./yr
1	Minneapolis	8310 (5260)	530 (370)	38	25	--	3	$1,160	1.38	98.3	28.9
2	Chicago	6130 (3540)	930 (620)	38	25	--	3	$1,190	1.52	54.6	16.1
3	Portland	4790 (1840)	300 (1010)	38	19	19	3	$1,050	1.87	34.9	10.3
3	Washington, D.C.	4210 (1980)	1420 (1010)	38	19	--	3	$ 900	1.79	37.7	11.1
4	Atlanta	3100 (1230)	1590 (1130)	38	19	11	3	$1,330	1.82	27.0	7.9
4	Fresno	2650 (770)	1670 (1220)	38	19	--	3	$1,280	2.02	28.6	8.4
5	Burbank	1820 (170)[b]	620 (310)[b]	30	11	--	2	$ 520	2.02	4.6	4.3
6	Phoenix	1550 (320)	3510 (2960)	38	19	--	3	$1,280	1.92	36.0	10.6
6	Houston	1430 (360)	2890 (2240)	38	19	--	3	$1,280	1.83	28.5	8.4
7	Ft. Worth	2830 (810)	2590 (2030)	38	19	--	3	$1,280	1.83	33.9	10.0

[a]Heating and cooling degree-days base 65°F presented; heating degree-days base 53°F in parentheses; cooling degree-days base 68°F in parentheses.
[b]Degree-days for Los Angeles reported.

Table 6. Illustrative ways of meeting the design energy budgets for single family residences in three locations: electric heated homes.

Location	Sets of Options
Chicago, IL	1. Average window area and distribution;[a] triple glazing;[b] R-38 ceiling and R-25 wall insulation; heating supplied by a heat pump.
	2. Windows redistributed so that south facing window area increased by 36% and east, west, and north facing window area decreased by 12%; triple glazing; R-38 ceiling and R-19 wall insulation; heating supplied by heat pump.
	3. Active solar domestic water heating system;[d] double glazing; R-38 ceiling and R-25 wall insulation; heating supplied by electric resistance.
Atlanta, GA	1. Average window area and distribution;[a] triple glazing;[b] R-38 ceiling, R-19 wall, and R-11 floor[c] insulation; heating supplied by heat pump.
	2. Windows redistributed so that south facing window area increased by 80% and east, west, and north facing window area decreased by 27%; double glazing; R-38 ceiling, R-19 wall, and R-11 floor[c] insulation; heating supplied by heat pump.
	3. Active solar domestic water heating system;[d] double glazing; R-30 ceiling, R-19 wall, and R-11 floor[c] insulation; heating supplied by electric resistance.
Houston, TX	1. Average window area and distribution;[a] triple glazing;[b] R-38 ceiling and R-19 wall insulation; heating supplied by heat pump.
	2. Active solar domestic water heating system;[d] R-19 ceiling and R-11 wall insulation.

[a]The average window area is 15% of total floor area. The windows are distributed equally among the exterior walls.

[b]Double glazing plus storm windows can substitute for triple glazing with little change in the Design Energy Consumption of the house.

[c]Floor insulation is noted in Atlanta, Georgia, and all other areas where crawl-space basements are used.

[d]The active solar domestic water heating is assumed to be sized at 60% of the water heating load in a 1500 square foot house for the purpose of this illustration.

venting through a heat exchanger), then

- a reduction of 50% to 60% in average energy use for residential space conditioning (from current building practice) can be accomplished. This is a reduction of 75% to 85% from the energy use of an average existing house;
- this requires an increased initial investment of \$0.75 to \$1.50 per square foot.
- the net savings is \$1500 to \$4000 to the new house owner, in addition to a higher selling price of the house.

PLANNED ACTIVITIES FOR 1980

The BEPS program at LBL has been expanded for Fiscal Year 1980. The following activities are either underway or planned:

1. Analysis in support of Final Rulemaking:
    - development of new prototype,
    - detailed assessment of the economics and thermal performance of residential heating and cooling equipment (including heat pumps) and water heaters,
    - application of life-cycle costing to heating and cooling equipment, water heaters, and the building envelope,
    - continued analysis of the economics and energy performance of exterior masonry walls,
    - final computer curves of conservation measures for four prototypes in 32 locations,
    - sensitivity studies of the effects of changing window size and orientation, conservation measures, internal thermal mass, and other building characteristics,
    - continuing analysis of the impact of uncertainty in key economic parameters on the development of the standards (see paper by P. P. Craig, M. D. Levine, and J. Mass on this subject in Energy, in press),
    - study of other key issues related to the promulgation and implementation of standards:

      --computer program comparison and validation,
      --credits for the use of renewable resources,
      --assessment of how many energy budgets are needed,
      --continued analysis of how energy budgets for different fuels are compared.
2. Planning of energy conservation research to support an update of the standards in 1985.
3. Research on selected advanced energy conservation measures, including infiltration with mechanical ventilation through a heat exchanger, direct gain passive solar, and advanced concepts for energy conservation in windows.
4. Support for DOE in its analysis of commercial buildings and mobile homes.
5. Participation in DOE's public information program on the Building Energy Performance Standards.

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16. A. Gadgil, D. Goldstein, and J. Mass, "A Heating and Cooling Loads Comparison of Three Building Simulation Models for Residences: TWOZONE, DOE-1 and NBSLD," Proceedings of the International Conference on Energy Use Management II, Los Angeles, October, 1979.

PUBLICATIONS LIST

The publications list through September 1979 for the Energy Efficient Buildings Program is organized as follows:

ENERGY EFFICIENT BUILDINGS (EEB) - general reports not specific to any sub-group.

BUILDING ENERGY ANALYSIS GROUP (BEAG - including DOE-2) - reports concerning computer modelling and programming. (GR stands for GROUP REPORT, and represents an internal document).

BUILDING ENERGY PEERFORMANCE STANDARDS (BEPS) - reports specific to the proposed Federal Building Energy Performance Standards.

ENERGY CONSERVATION INSPECTION SERVICE (ECIS) - contains reports concerning the ECIS program.

ENERGY PERFORMANCE OF BUILDINGS - reports specific to the energy performance of building envelopes.

HOSPITALS - reports related to the Hospitals Program.

SCHOOLS - reports specific to the Schools Program.

VENTILATION - reports specific to building ventilation and indoor air quality.

WINDOWS - reports specific to the energy-efficient design of windows

LIGHTING - reports specific to the energy-efficient design of lighting systems, including daylighting.

All reports have an LBL number, which may be used for ordering copies of the report.

A longer form of this list, including abstracts, is also available.

ENERGY EFFICIENT BUILDINGS (EEB)

1976

EEB 76-1, LBL-3274, PROJECTING AN ENERGY-EFFICIENT CALIFORNIA. D.B. Goldstein and A.H. Rosenfeld, 1976.

EEB 76-2, LBL-4438, CONSERVATION AND PEAK POWER - COST AND DEMAND. D.B. Goldstein and A.H. Rosenfeld, 1976.

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EEB 77-2, MODELING NATURAL ENERGY FLOW IN HOUSES. E. Dean and A.H. Rosenfeld, chapter 3 of above journal.

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EEB 77-4, BEAM DAYLIGHTING. A.H. Rosenfeld and S. Selkowitz, chapter 4.

EEB 77-5, ENERGY COST OF BUILDINGS. R.A. Herendeen and A.H. Rosenfeld, chapter 8.

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EEB-BEV 78-3, LBL-6865, SAVING HALF OF CALIFORNIA'S ENERGY AND PEAK POWER IN BUILDINGS AND APPLIANCES VIA LONG-RANGE STANDARDS AND OTHER LEGISLATION. A.H. Rosenfeld, D.B. Goldstein, A.J. Lichtenberg, and P.P. Craig. Submitted to the California Policy Seminar, May 1978.

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