Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

BUILDING VENTILATION AND INDOOR AIR QUALITY PROGRAM

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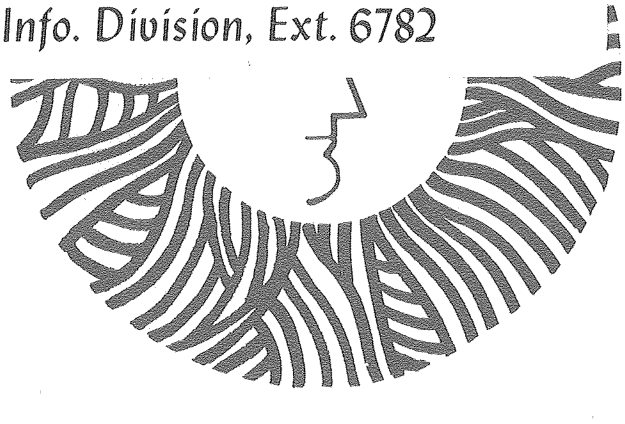

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LBL-9284
EEB-Vent 79-6

BUILDING VENTILATION AND INDOOR AIR QUALITY PROGRAM

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Building Ventilation and Indoor Air Quality

Craig D. Hollowell

Introduction

This is the second annual report on the research activities of the Building Ventilation and Indoor Air Quality (BV/IAQ) Program at the Lawrence Berkeley Laboratory (LBL). The research is supported by the Office of Buildings and Community Systems, Assistant Secretary for Conservation and Solar Applications and the Office of Health and Environmental Research, Assistant Secretary for Environment of the U.S. Department of Energy (DOE) under contract No. W-7405-ENG-48.

The BV/IAQ Program, formed in FY 1977 has grown quite rapidly in response to the need for research on energy efficient building ventilation systems compatible with the health and comfort requirements of building occupants. The BV/IAQ Program is a major component of the Energy Efficient Buildings Program at LBL.

This report is divided into three sections. The first section on the Ventilation Program, funded by the Office of Buildings and Community Systems of DOE, represents the major part of the BV/IAQ Program. The second section discusses the Indoor Air Quality research supported by the Office of Health and Environmental Research of DOE. The third section presents the activities of the Hospitals Program, a closely allied program within the Energy Efficient Buildings Program. The Hospitals Program, also funded by the Office of Buildings and Community Systems, includes a large study on hospital ventilation requirements.

Ventilation Program

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INTRODUCTION

The Ventilation 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), the Ventilation 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.

LBL Ventilation Program activities for 1978 can be categorized as follows:

1) field monitoring of indoor air quality;

2) laboratory studies of building materials emissions;

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

4) additional subcontract activities consisting of:

   - assessment of ventilation requirements for odor control in buildings;
   - reassessment of hospital ventilation standards;
   - field survey of current practices in enforcement of ventilation regulations;
   - study of automatic variable ventilation control systems based on air quality detection in institutional and commercial buildings.

5) development of a ventilation data base.

Residential, institutional, and commercial buildings together account for approximately one-third of the energy consumed annually in the United States, as shown in 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 ventilation 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

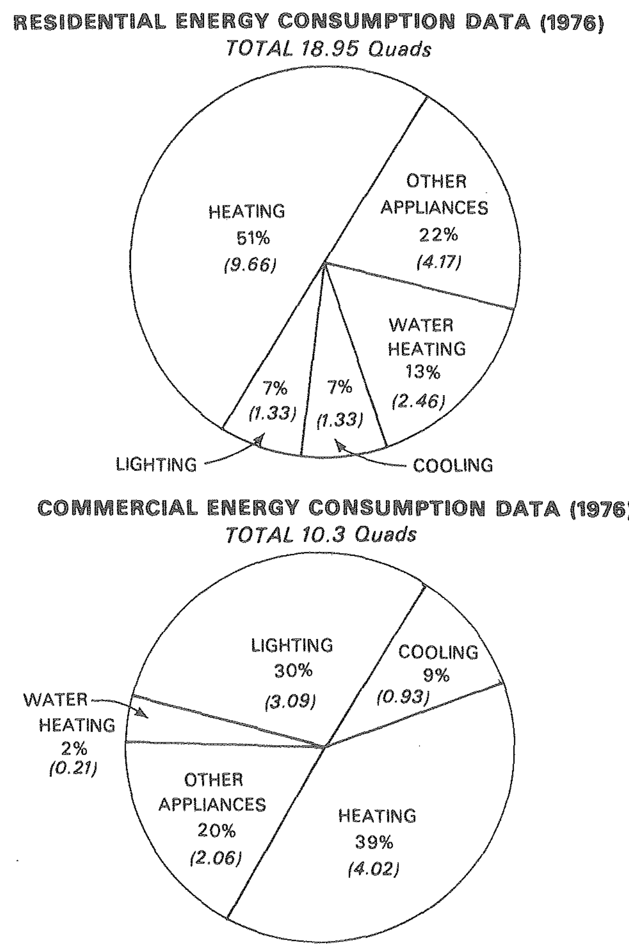


Fig. 1. Primary energy consumed in the U. S. by residential and commercial buildings. Numbers in parentheses are in units of quads or 10^{15} Btu. Source: Department of Energy, Office of Conservation, Buildings and Community Systems, Five Year Program Plan. (XBL 785-903)

ventilation or mechanical ventilation. In the United States, the latter mechanism is essentially limited to non-residential buildings. Ventilation, in general, is required for the following reasons:

- Establishment of a satisfactory balance between the metabolic gases (oxygen and carbon dioxide) in the occupied environment.
- Dilution of human and nonhuman odors to a level below an unacceptable olfactory threshold.
- Removal of contaminants produced in the ventilated space by heating, cooking, construction materials, etc.
- Removal of excess heat and moisture from internal sources.

Ventilation requirements are currently set by state and local governments and are found to vary from one jurisdiction to another. Most of the existing building codes, wherein ventilation requirements are found, 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 Housing and Urban Development (HUD), and the Department of Energy (DOE) are working together to develop these standards. The Ventilation Program is performing research necessary for understanding ventilation requirements as part of the effort to develop building energy performance standards.

Since the heating or cooling of outside air as it is introduced into a building requires a significant amount of energy, a large fraction of the potential energy savings in buildings can be accounted for by minimizing the use of fresh ventilation air. Table 1 illustrates the magnitude of these possible savings. An energy savings of one million barrels of oil per day (2 quads* per year) would result if ventilation requirements were relaxed and infiltration reduced so as to achieve a savings of 12.5% in the energy used to condition indoor air. 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] One way to achieve this potential energy savings of a million barrels of oil per day would be to "tighten" about two-thirds of existing residential buildings to reduce infiltration by a factor of about two, and to decrease the outside air requirements of about two-thirds of non-residential buildings by a factor of two.

*One quad equals 10^{15} BTU.

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

Total U.S. energy consumption	75×10^{15} BTU/yr
Total U.S. energy consumption for buildings	29×10^{15} BTU/yr
50% of building energy used to condition air (includes mechanical ventilation systems)	14.5×10^{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	2.2×10^{15} BTU/yr
2.5% of national energy budget (7.5% of building energy budget)	1.0×10^{6} barrels of oil/day
At present prices of $12/barrel	Savings of $12 million/day
At estimated 1985 prices of $25/barrel	Savings of $25 million/day

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

The introduction of energy-saving measures in buildings, however, may adversely affect indoor air quality. But there is a little agreement on the levels of fresh air required for the health and comfort of building occupants. The U.S., unlike some European countries, has no mandatory air quality standards developed specifically for the indoor environment. 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.

Previous research at LBL on the impact of combustion-generated indoor air pollution concluded that it is essential to consider the impact of reduced ventilation on indoor air quality.[2,3] This research has shown, among other things, that typical gas stoves operating under current design conditions produce unacceptably high concentrations of noxious pollutants. An effort will be made to establish a scientific basis for ventilation standards and to provide data and recommendations for the establishment of energy-efficient ventilation standards in different classes of buildings.

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 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.

FIELD MONITORING OF INDOOR AIR QUALITY

(Berk, Brown, Ko, Koonce, Loo, Pepper, Turiel, Young)

In order to establish criteria for setting energy-efficient ventilation standards, the Ventilation Program staff is involved in a comprehensive assessment of indoor air quality in different types of buildings under a variety of ventilation conditions. Table 2 lists several indoor contaminants, identified as potential health hazards, and their sources. LBL is assessing a significant number of the pollutants shown.

The Ventilation Program staff is conducting field monitoring of indoor air quality at hospitals and educational facilities before and after energy conserving retrofits are implemented. In addition, prototype energy efficient residential homes and other buildings are being studied as possible models for energy conservation. The LBL Ventilation Program staff and subcontractors are measuring:

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

Table 2. Indoor air pollution in 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	Radon
Particleboard	Formaldehyde
Insulation	Formaldehyde
Adhesives	Organics
Paint	Mercury, Organics
Building Contents	
Heating and cooking combustion appliances	CO, SO_2, NO, NO_2, Particulates
Furnishings	Organics, Odors
Water service; natural gas	Radon
Human Occupants	
Metabolic activity	CO_2, NH_3, Organics, Odors
Human Activities	
Tobacco smoke	CO, NO_2, HCN, Organics, Odors
Aerosol spray devices	Fluorocarbons, Vinyl Chloride
Cleaning and cooking products	Hydrocarbons, Odors, NH_3
Hobbies and crafts	Organics

EEB Mobile Laboratory

The Energy Efficient Buildings (EEB) Mobile Laboratory[4] is a facility designed for field studies of ventilation requirements and energy utilization in buildings. The EEB Mobile Laboratory was equipped in early 1978 with the instrumentation listed in Table 3, in order to monitor the contaminants shown in the same table. The EEB Mobile Laboratory was designed to assist field monitoring efforts, and to facilitate R&D studies of ventilation requirements and energy utilization in residential, institutional, and commercial buildings.

The laboratory contains sampling, calibration, and monitoring systems which provide an index of the overall air quality in a building.

Table 3. 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

Air change rates are measured using a tracer gas system[5] (developed at LBL) in which nitrous oxide is injected and monitored continuously under controlled conditions at the sampling sites. This and the other continuously monitored 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 the LBL computer system.

The EEB Mobile Laboratory, shown in Exhibit 1, is positioned outside the building to be studied. Air from four locations within the structure is drawn through teflon sampling lines into the trailer for analysis. By sequentially sampling the lines (one of which is used to monitor outdoor ambient air), the air quality can be monitored in several rooms.

For some pollutants, grab sampling techniques are used. The size distribution of the particulate matter in the sampled air is measured by means of an optical scattering instrument and automatic dichotomous air samplers; the latter are also used to collect particulate matter for chemical analysis. The dichotomous air samplers,[6] developed at LBL, separate the aerosols into respirable and non-respirable fractions (below and above 2.5 micron size, respectively) using a flow-controlled virtual impaction system, which deposits the particulate matter on teflon filters. The particulates collected on the filters are analyzed at LBL using beta-ray attenuation to measure mass concentration, and x-ray fluorescence to determine chemical composition for 27 elements. Some of the contaminants must be collected with gas bubblers and other sampling techniques requiring subsequent laboratory analysis.

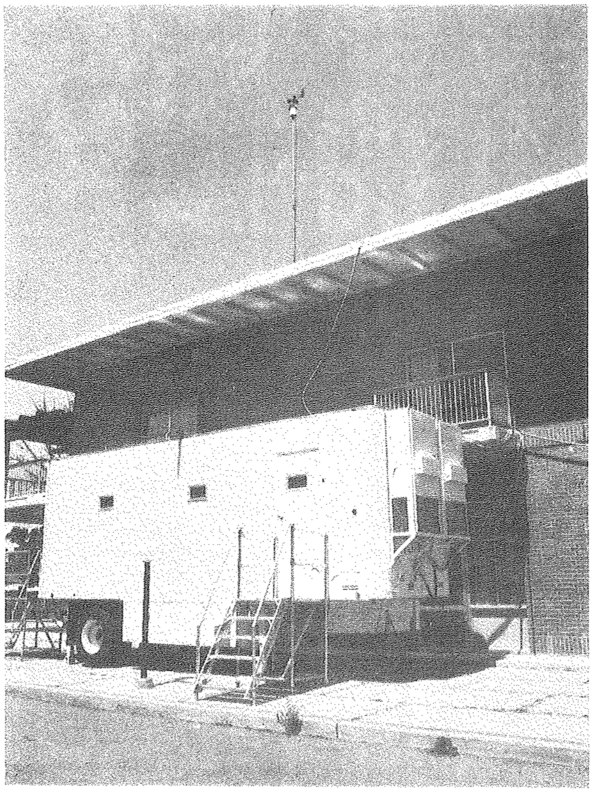


Exhibit 1. The EEB Mobile Laboratory.

These contaminants include radon, formaldehyde, total aldehydes, other selected organic compounds (shown in Table 4), and microbial content.

Field Monitoring

During 1978, four sites were included in the field monitoring program. Indoor air quality was monitored at Carondelet High School, an air-conditioned high school in Concord, California; at occupied and unoccupied Minimum Energy Dwellings (MED) in Mission Viejo, California; the Naval Regional Medical Center in Long Beach, California; and the Iowa State University Energy Research House in Ames, Iowa. Preliminary results from Carondelet indicate that the fresh air ventilation rate could be substantially reduced without compromising the health or comfort of the occupants. Data from the other three sites are currently being analyzed. At the MED houses and at the Iowa State University house, the indoor air quality is of considerable interest because these residential buildings were constructed to have low air infiltration. In the case of the Long Beach hospital, the air quality is being measured before and after energy-saving retrofits are implemented.

Carondelet High School is a two story air-conditioned building with about 40 classrooms and 700 occupants. The heating, ventilation and air conditioning (HVAC) system is a combination air-water type with room induction units. There is one air-supply fan for the air distribution system.

The fresh air entering the roof was measured, reduced, and regulated to save energy. Three of the four sides of the air intake unit intake dampers were sealed and an air-flow measuring device and flow controller were installed in the remaining side. The air quality in two classrooms, in a corridor, and outdoors was monitored under three ventilation rates. The first rate (20,000 cfm) was the normal operating mode, with roof dampers in the full open position. The second and third rates (3700 cfm and 2300 cfm, respectively) restricted total fresh air in the school. The decision to restrict the fresh air to 2300 cfm was not made until it had been established that the indoor air quality at 3700 cfm was still very good. In a typical classroom with twenty students, these ventilation rates correspond to 18 cfm, 3.3 cfm and 2.1 cfm fresh air per person. Data were collected for the three fresh air ventilation rates indicated. Carbon dioxide was the only pollutant detected in significant concentrations inside the school. This is not surprising, since there were no obvious indoor sources of pollution other than the occupants themselves. The school borders on a main thoroughfare; during rush hour periods when increased levels of nitrogen oxides and ozone were present outdoors, smaller but measurable concentrations were observed indoors. Indoor concentrations of these pollutants actually decreased as the "fresh" air ventilation rates were reduced.

Figure 2 shows the CO_2 buildup and decline during a typical day at the restricted fresh air ventilation rate of 3700 cfm for the entire school. Concentrations in the two classrooms and outdoors are shown. Although CO_2 concentrations inside the classroom increased as ventilation rates were lowered, at no time did they exceed 2000 ppm, and only occasionally did they exceed 1500 ppm. This should be compared to the National Institute for Occupational Safety and Health (NIOSH) recommended ten-hour maximum of 10,000 ppm;[7] the American Conference of Governmental Industrial Hygienists (ACGIH) recommended 8-hour maximum of 5000 ppm;[8] and the Occupational Safety and Health Administration (OSHA) recommended 8-hour maximum of 5000 ppm.[9] These concentrations refer to a time weighted average concentration for up to 8 and 10 hour workshifts in a 40

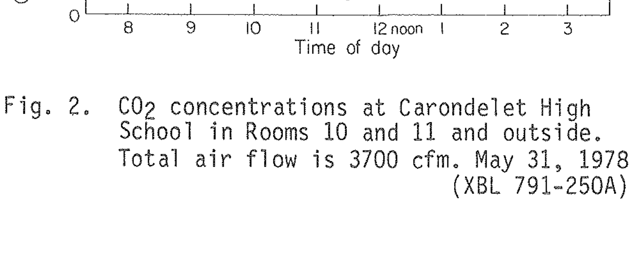


Fig. 2. CO_2 concentrations at Carondelet High School in Rooms 10 and 11 and outside. Total air flow is 3700 cfm. May 31, 1978. (XBL 791-250A)

Table 4. Tentative list of indoor organic air contaminants to be sampled by either Tenax GC sampling tubes for gas chromatographic analysis or gas bubblers for wet chemistry analysis.

Compounds	Health Effects	Possible Sources and/or Uses
C_n Alkanes N = 5 ∿ 16	Narcotic at high concentrations; moderately irritating	Gasoline, mineral spirits, solvents, etc.
C_n Alkenes N = 5 ∿ 16	Similar to that of alkanes	Similar to that of alkanes
Benzene	Respiratory irritation; recognized carcinogen	Plastic and rubber solvents; from cigarette smoking; used in paints and varnishes, including putty, filler, stains and finishes
1,1,1-Trichloroethane	Subject of OSHA carcinogenesis inquiry	Aerosol propellant, pesticide, cleaning solvents
Trichloroethylene	Animal carcinogen; subject of OSHA carcinogenesis inquiry	Oil and wax solvents, cleaning compounds, vapour degreasing products, dry cleaning operations; also used as an anaesthetic
Toluene	Narcotic; may cause anemia	Solvents; by-product of organic compounds used in several household products
Ethyl Benzene	Highly irritating to eyes, etc.	Solvents; used in Styrene related products
Xylene	Narcotic; irritating; high concentrations may cause injury to heart, liver, kidney, and nervous system	Used as solvent for resins, enamels, etc.; also used in non-lead automobile fuels and in manufacture of pesticides, dyes, pharmaceuticals
Styrene	Narcotic; can cause headache, fatigue, stupor, depression, incoordination and possible eye injury	Widely used in manufacture of plastics, synthetic rubber and resins
Chloro Benzenes	Strong narcotic; possible lung, liver, and kidney damage	Used in production of paint, varnish, pesticides, and various organic solvents
Polychlorinated Biphenyls (PCB's)	Suspected carcinogens	Used in various electrical components; may appear in waste oil supplies and in plastic and paper products in which PCB's are used as plasticizers
Formaldehyde and other Aldehydes	Eye and respiratory irritation; may have more serious long term health effects	Out-gassing from building materials -- particle board, plywood and urea-formaldehyde insulation foam; also generated by cooking and smoking

hour work week. Studies have shown that workers may be repeatedly exposed to these concentrations day after day without adverse health effects.[7]

To assess the potential reaction of the students to the changes in ventilation rates, a questionnaire on the quality of the indoor environment was designed and distributed to the occupants of two classrooms. Exhibit 2 is a sample questionnaire. The students' subjective judgment of odor level at various ventilation rates was of particular interest since odor control is probably the basis for current ventilation requirements in most schools. The questionnaires were filled out every other day at the same time and the results from one classroom are shown in Fig. 3. The subjective rating ranged from 1 to 9 with lower numbers corresponding to the first adjective in parenthesis. For example, for odor intensity the high numbers would indicate strong odor perception, whereas low numbers would indicate little or no odor perception. As can be seen in the figure, odor intensity essentially remained constant at all of the ventilation rates shown. There was a significant correlation between temperature and air movement. Subjective evaluation of both variables changed substantially over time.

Date__________ Room No.__________

Male_____ Female_____

No odor __:__:__:__:__:__:__:__:__ Strong odor
1 2 3 4 5 6 7 8 9

Pleasant odor __:__:__:__:__:__:__:__:__ Unpleasant odor
1 2 3 4 5 6 7 8 9

Cold __:__:__:__:__:__:__:__:__ Hot
1 2 3 4 5 6 7 8 9

Drafty __:__:__:__:__:__:__:__:__ Stuffy
1 2 3 4 5 6 7 8 9

Humid __:__:__:__:__:__:__:__:__ Dry
1 2 3 4 5 6 7 8 9

Quiet __:__:__:__:__:__:__:__:__ Noisy
1 2 3 4 5 6 7 8 9

Exhibit 2. Quality of indoor environment questionnaire submitted to student occupants of Carondelet High School.

During 1978, Carondelet was also one of the two sites included in the biological field monitoring project. This work is being performed by the Naval Biosciences Laboratory (NBL), under subcontract to LBL. The purpose of the project is to generate scientific and technical information pertaining to the sampling, assay, and data analysis of airborne bacteria in several of the facilities in which field monitoring is being carried out. Utilizing the data gathered, efforts will be made to determine whether the implementation of ventilation-related conservation retrofits gives rise to unacceptably high levels of airborne microbes. The analysis of the data is based primarily upon the magnitude of the changes in the number and size of the microorganisms present before and after ventilation rates have been reduced.

The bacterial content of the air is measured by modified Andersen samplers[10] fabricated and operated by NBL. These devices collect airborne particles on 6 size-selecting plates of Agar nutrient media. Living microbes on or in such particles will, within two days, grow to such an extent that a visible spot (colony) will appear on the surface of the medium, and the colonies can be counted.

INDOOR AIR QUALITY QUESTIONNAIRE RESULTS - CARONDELET HIGH SCHOOL

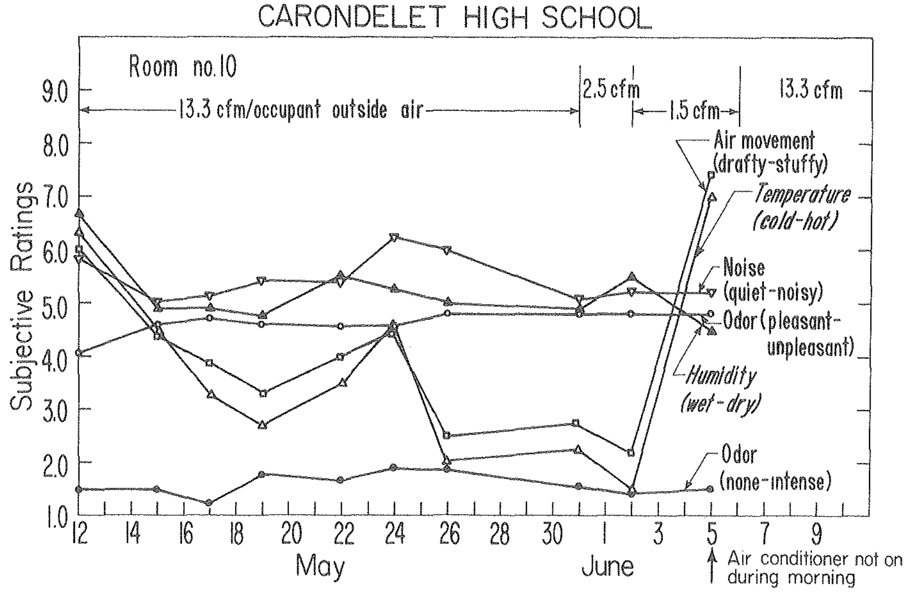


Fig. 3. Six indoor air quality parameters plotted as a function of day of month and ventilation rate. Data taken from questionnaire. The subjective rating ranged from 1 to 9 with lower numbers corresponding to the first adjective in parentheses. (XBL 791-251A)

One of the three sampling points at the field site is also equipped with an optical particle size analyzer such that the total number of airborne particles in selected size ranges (e.g., 0.8 to 2, 2-4, 4-7, 7-10, and greater than 10 µm in diameter) can be recorded. NBL will attempt to establish whether the data are correlated with Andersen sampler data in order to determine if an instrument of this type would be suitable for general microbial burden monitoring.

The raw data appear in the form of numbers of colonies per stage. They may be transformed to percent of the total sample per stage, and the cumulative percentage distribution plotted on a log-probit grid, shown in Fig. 4, from which the number median diameter (NMD) can also be obtained. Data are presented in the form of numbers of colony-forming particles (CFP)* per cubic meter of air. As the study proceeds, these values will be correlated with ventilation rates and other factors such as temperature and relative humidity.

A summary of microbial data from Carondelet High School is shown in Table 5. There is an increase in the number of CFP/m^3 and in the NMD of the particles with occupant density. This is consistent with theory since CFP originating from human activity (i.e., mostly skin shedding) tend to be larger than those from other sources.

*An airborne particle may contain many or no viable bacteria. The presence of a colony after the sample medium is incubated indicates the collected particle had at least one viable cell; how many more cells may have been present cannot be ascertained. Hence they can only be referred to as "colony forming particles" rather than bacterial numbers.

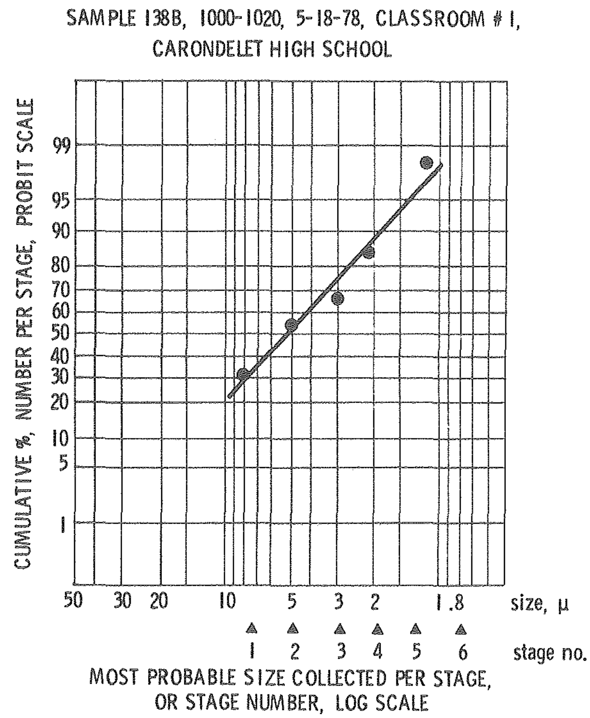


Fig. 4. Example of treatment of typical sample for analysis of particle size. Numbers of colonies found on each stage are totaled, and the percentage of the total number is determined for each stage. The cumulative percentages are plotted on a probit scale vs. log of size. The 50 percentile size is the Number Median Diameter (NMD), in this instance 3.5 m. The log scale is chosen because the data most often conform to a straight-line relationship on a log-normal basis.

Table 5. Summary of data on airborne/colony forming particles collected at Carondelet High School (Based on 114 samples).

Fresh Air* Exchange Rate (cfm)	Room 1 (CFP/m^3)		Room 2 (CFP/m^3)	
	Occupied	Unoccupied+	Occupied	Unoccupied+
18	160(5.4)	54(4.3)	107(5.4)	27(2.4)
2.7	115(6.6)	47(3.5)	75(5.8)	37(2.8)

+ = 0700 sample; ventilation turned on at 0630.

( ) = The Number Median Diameter (NMD) in m (10^{-6}m).

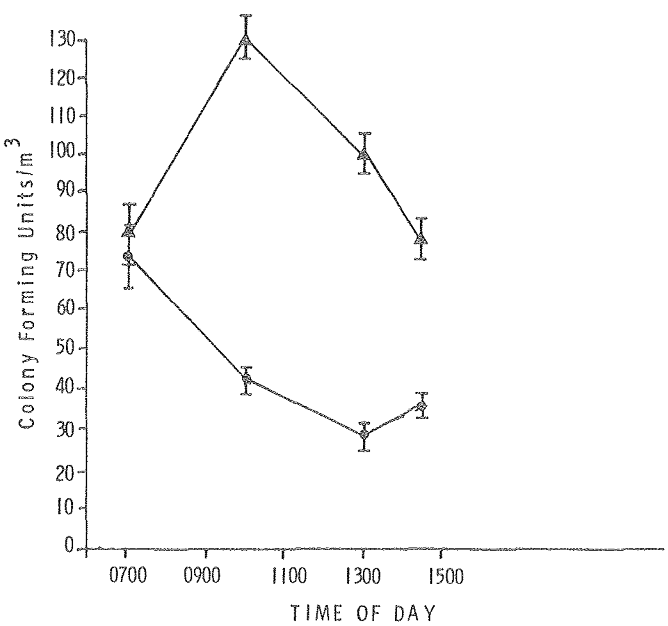
* = Fresh air per person for average of 20 students.

However, only the rise in NMD appears to be statistically significant.

It is not known why the number of airborne bacteria is consistently higher in Room 1 than in Room 2. Surprisingly, an increase in the amount of fresh air almost always produced an increase in the number of viable airborne molecules. This result was unexpected and tends to indicate that there might be a significant source of bacteria in the outside air.

The change in number of CFP/m^3 as a function of time of day is shown in Fig. 5. It can be seen that the respirable burden (particles 5 μm in diameter or less) was greatest at 7:00 a.m. and declined during the day. The total number of microbes increased markedly between 7:00 and 10:00 a.m. One possible explanation is that there were two populations of airborne bacteria in the school: one (large-size CFP's) arising and the other (respirable CFP's) decreasing during the day. No firm conclusion about the variations or airborne bacteria with time and ventilation rates can be made with these limited data. The results at Carondelet do show, however, that decreasing the ventilation rate did not increase the microbial burden in the classrooms.

Results of the field monitoring project at Carondelet High School indicate no significant change as a result of decreased ventilation in any of the parameters measured, with the exception of carbon dioxide. While CO_2 levels increased, concentrations were still far below levels considered to be a health hazard. In fact, the air quality improved in the school for some parameters (nitrogen dioxide and ozone) when the ventilation rate was reduced. Results of the survey of subjective impressions of indoor air quality showed no deterioration of student comfort caused by decreased ventilation rates.



"RESPIRABLE BURDEN" (PARTICLES 5 μm IN DIAMETER OR LESS) AT CARONDELET HIGH SCHOOL (●) AND TOTAL NUMBERS (▲).

Fig. 5. Respirable and total number of colony-forming particles are shown as a function of time of day.

Since the amount of outside air entering the school could be decreased without any adverse affect on the health, safety, or comfort of the occupants, substantial energy savings could be achieved by lowering the fresh air ventilation rates at Carondelet.

Total energy use for this high school in Concord, CA, including gas and electricity (used for space conditioning, lighting and hot water) costs about $40,000 per year. If the ventilation rate were changed from 20,000 cfm to 2,300 cfm, it is estimated that savings would amount to $3500 to $4000 per year or 9% of total annual energy costs for the building.

Educational facilities in the U.S. consume approximately 1.8 x 10^{15} Btu per year (1.8 quads), which amounts to 2.4% of total U.S. energy use. Space heating and cooling requirements consume about 2/3 of the energy budget of an average school. A significant portion of the energy is used to heat or cool incoming outside air. If we assume that one third of the heating, ventilation, and air conditioning (HVAC) system energy is used to condition outside air, then the total energy used to condition outside air in schools is approximately 0.4 x 10^{15} Btu or 0.4 quads. Decreasing ventilation requirements by a factor of two in schools results in a nation wide savings of 0.2 x 10^{15} Btu, or more than 10% of the total energy used in educational buildings. Thus, there are large potential energy savings to be realized by reducing the amount of outside ventilation air.

Analyses of the data from the Naval Regional Medical Center and the energy-efficient residential buildings are currently in progress.

Planned Activities for 1979

The following sites will be included in the field monitoring study of indoor air quality during 1979:

- Fairmoore Elementary School, Columbus, Ohio
- Energy Efficient House, Carroll County, Maryland
- LBL Research House, Walnut Creek, California
- Minimum Energy Dwelling II (Production Model) and Conventional House, Mission Viejo, California
- Naval Regional Medical Center (post retrofit), Long Beach, California
- Veterans Administration Hospital, Omaha, Nebraska (pre- and post-retrofit)
- School (to be determined), New York City.

STUDIES OF BUILDING MATERIALS EMISSIONS

As buildings are "tightened up" to reduce air infiltration, thus reducing energy requirements, there is an increased risk that contaminants emitted from building materials and generated by indoor activities (such as smoking and cooking) may remain inside buildings in concentrations hazardous to the health of of the occupants. The Ventilation Program staff has begun to identify contaminant emissions from building materials to determine the contaminant source strengths and to recommend and verify means for the energy efficient controls of these emissions. The studies have focused on two major categories of potentially hazardous substances:

- radon, a naturally occurring radioactive trace element found in most rock and soil, and
- organic vapors originating from indoor and outdoor sources

RADON

(Berk, Boegel, Nazaroff, Stitt, Zapalac)

The Ventilation Program staff is currently active in two areas of radon measurement: development of passive monitors for integrated measurements, and development of a chamber and Lucas cells[12] for laboratory measurements of radon emanations from building materials.

Radon and its decay daughters have always been present as part of the natural radiation burden; however, since radon emanates from indoor sources, reduced ventilation will lead to higher indoor concentrations and the attendant increased radiation exposure to lung tissue.[11] The possible increased risk of disease, especially lung cancer, must be considered when adopting building energy conservation standards. The risk should be assessed in the context of the naturally occurring exposure to radon daughters and the possible health impact of this exposure to the general population. Measures such as air-to-air heat exchangers (see below) and ventilated crawl spaces are available to limit increases in indoor radon daughter concentrations indoors while still achieving energy conservation in buildings.

Radon-222 is an inert, radioactive, naturally occurring gas which is part of the uranium-238 decay chain. Any substance that contains radium-226, the precursor of radon, is a potential emanation source. Since Ra-226 is a trace element in most rock and soil, indoor radon sources include concrete, brick, and other building materials. Ra-226 has a half-life of 1602 years and its presence in building materials results in a continuous source of radon for the life of the building. Other potentially significant sources of radon in buildings include the soil beneath the foundation and the tap water, especially if the water is taken from wells or underground springs in areas where significant amounts of radium are present.

The alpha decay of Ra-226 produces a chemically inert, recoiling radon-222 atom which has a 3.8 day half life. If the atom ends its recoil in an interstitial space of the solid source material, it may migrate to the surface and enter the air. Radon has four short-lived daughters, each with a half-life of less than 30 minutes. Figure 6 shows the decay chain for radium-226. The subsequent production of Pb-210, with a 22-year half-life, effectively ends the sequence as far as biological effects are concerned.

The four radioactive daughters of radon are not inert. Most attach themselves by chemical or physical means to airborne particulates, generally less than a micron in size. These particulates, when inhaled, may be retained in the lung bronchi, where subsequent decay to Pb-210 results in a radiation dose to the lung. The primary hazard is due to the alpha emission of polonium-213 and polonium-214. Since alpha particles have a very short range (a few tens of microns) in tissue, essentially all of the energy is deposited near the surface of the lung.

Radon emanation rates vary widely from one substance to another. Indoor levels are strongly affected by the manner in which materials are incorporated into a building, and by other aspects of the building's design, particularly the infiltration and ventilation rates.

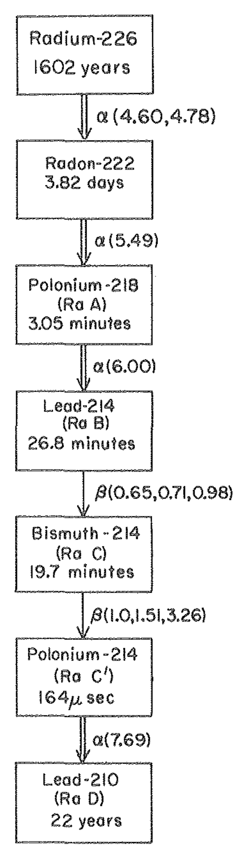


Fig. 6. Decay chain, radium-226 to lead-210 (α, β energies in MeV). (XBL 7212-4903B)

Passive Monitors for Integrated Measurements

Two dozen passive monitors[13] for integrated measurements of radon levels were fabricated in 1978. The LBL passive monitor, shown schematically in Fig. 7, is cylindrical in shape, approximately 8 inches in diameter and 12 inches high. The sensitive volume is defined by a metal funnel and perforated steel screen. A rubber stopper with a brass electrode is placed in the neck of the funnel. A lithium flouride, thermoluminescent dosimeter (TLD) chip is held in place above the end of the electrode by a molded plastic holder. Three 300 V dry cells provide -900 V to the electrode with the funnel and screen as reference.

Radon gas is driven by diffusion to a concentration in the sensitive volume equal to that in the surrounding air. Radon atoms which decay via alpha emission form positively charged Po-218 ions. The electric field in the sensitive volume attracts these Po-218 ions towards the electrode, where they are deposited on the TLD chip. Since the Po-218 collection efficiency of the instrument is humidity dependent, the 3" desiccant bed is needed to provide a constant, low humidity environment in the sensitive volume. Subsequent alpha decays of Po-218 and other short-lived radon daughters are recorded by the chip. After a one or two week sampling period, the chip is sent back to LBL for readout.

When a thermoluminescent material is exposed to ionizing radiation, electron hole pairs are generated, some of which enter metastable states above the ground state. These metastable states have potential energy wells deeper than room

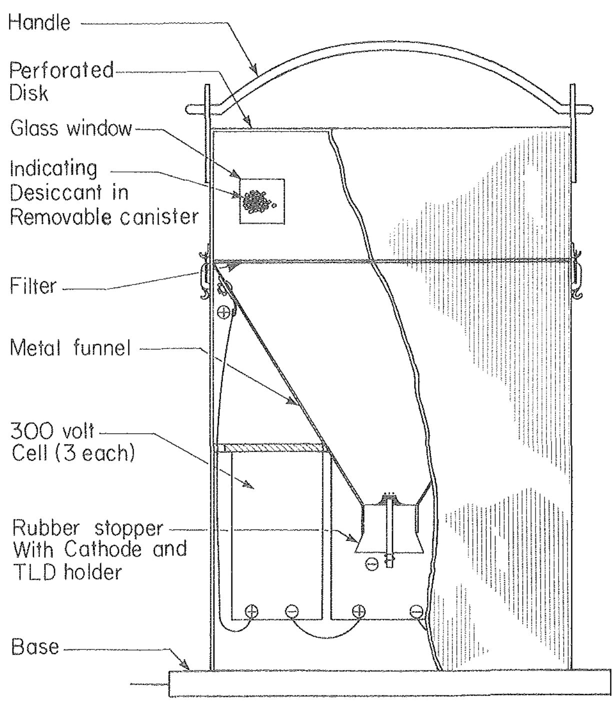


Fig. 7. Schematic drawing of Passive Radon Monitor. (XBL 791-252)

temperature thermal energy, so the electron hole pairs do not recombine until additional thermal energy is supplied. A photon is emitted when the atom returns to its ground state. The procedure for determining alpha exposure is to heat the chips in a prescribed manner and measure the light emitted using a photomultiplier (PM) tube. The PM tube current is proportional to the integrated radon concentration during exposure.

Radon Emanations from Building Materials

In addition to the studies using passive radon monitors, laboratory studies are being conducted to measure the rates at which radon emanates from various building materials. Air-tight chambers are being fabricated into which building materials will be placed. By measuring the radon buildup in the chambers, radon emanation rates can be determined. Materials to be studied in 1979 include concrete of varying composition and origin, brick, and gypsum board.

The airtight chambers are aluminum, 15 inches on a side, and have shelves for the placement of slabs of the material being studied. A tedlar bag approximately two liters in volume is attached to the chamber to allow daily air samples to be withdrawn without reducing the pressure inside the chamber. The air samples are transferred into Lucas cells fabricated at LBL. These cells are 2-inch diameter copper flasks of 100 cc. volume, coated on the inside with zinc sulfide phosphor and having a quartz window adhered to one end to allow light transmission. These flasks are vacuum pumped and then filled with the chamber air containing radon. After allowing a few hours for radioactive equilibrium to occur between the radon gas and its daughters, the cells are placed on a photomultiplier tube counting system to count alpha particles produced in the flasks. From these counting rates, the radon concentration can be calculated.

ORGANIC CONTAMINANTS

(Lin, Anaclerio, Anthon, Fanning, Wiebe)

The Ventilation Program staff began its study of organic vapors in the indoor environment in 1978. Two approaches are being used: field monitoring of the air in various indoor environments, and laboratory analyses of emissions from building materials.

The results of LBL studies and other work[14-16] indicate that air in various indoor environments is contaminated with a range of organic vapors that originate from indoor and outdoor sources. Inside buildings, organic vapors, e.g., formaldehyde can be emitted from common building materials such as urea-formaldehyde foam insulation, plywood, and particle board.[16] Adhesives, used in forest products and other furnishings, are also sources of such emissions. Indoor activities (such as cooking, cleaning and smoking) can also generate organic contaminants.

Many of these volatile organic contaminants are known to have serious health effects. Because of their chemical complexity and extremely low concentrations, the hazardous organics found in the air are very difficult to measure quantitatively. Instruments for continuous monitoring are not currently available for measuring most organic contaminants in ambient air. It is therefore necessary to use appropriate adsorbing materials to concentrate these organics in the field for laboratory analysis. To date, little work has been done on sampling and analysis of organics in non-occupational indoor environments. Thus, major efforts are required to develop capabilities in analyzing airborne trace organics for indoor air quality studies.

Analytical Techniques

A chemistry laboratory has been equipped with high resolution analytical instruments for the studies at LBL. The facility includes:

1) a Varian 3711 Gas Chromatograph (GC) with a Flame Ionization Detector (FID) and Electron Capture Detector (ECD)

2) a Varian Cary 219 UV/Visible Spectrophotometer

3) a Finnigan 4023 GC/MS (with INCOS data system)

Based on an extensive literature search, a list of indoor organic contaminants, shown in Table 4, has been developed for study. Compound selection was based on possible indoor source strengths as well as the seriousness of the health risks posed by exposure.

The Ventilation Program staff has adopted gas chromatographic techniques for the separation of most of the selected volatile organics shown in Table 4. Polymer resins (e.g., Tenax GC, XAD2) will be used as adsorbents to collect ambient organic vapors in the field. The adsorbed sample will be either extracted with suitable solvents or thermally desorbed at high temperatures. Splitting the column effluent into ECD and FID fractions allows simultaneous detection of halogenated and non-halogenated compounds. To identify the compounds on the chromatogram, internal standards will be added to the adsorbent and relative retention times will be studied. Frequently, gas chromatographic techniques will be used in conjunction with mass spectrometric techniques (GC/MS) to confirm the identity of the isolated compounds.

The Ventilation Program staff has developed and fabricated a grab sampling control system for taking accurate air samples. These samples are taken over periods of eight hours in the daytime and sixteen hours in the nighttime. The grab sampling control system, shown in Fig. 8, is currently used in conjunction with four gas bubbler systems for sampling formaldehyde and total aldehydes. In the field, indoor and outdoor air are sampled with a 0.05% MBTH solution for collection of total aldehydes. Simultaneously, distilled water is used to collect samples in order to compare the MBTH, pararosaniline and chromotropic acid analytical methods and to determine the formaldehyde concentration of the total aldehydes.

The sampling procedure developed at LBL is a modified version of the standard methods recommended by various government agencies. The precision and accuracy of the LBL method is an improvement over traditional techniques. At sampling points, air is drawn through a sintered coarse glass frit (70 to 100 μ pore size) for effective aldehyde collection. The air sample is then passed successively through a cool demister, a pair of filters, and plastic tubing to a control system located in the EEB Mobile Laboratory. From there the air travels through a flow regulator, a fine needle valve, a rotameter, a vacuum regulator, pressure gauges, and a diaphragm pump system.

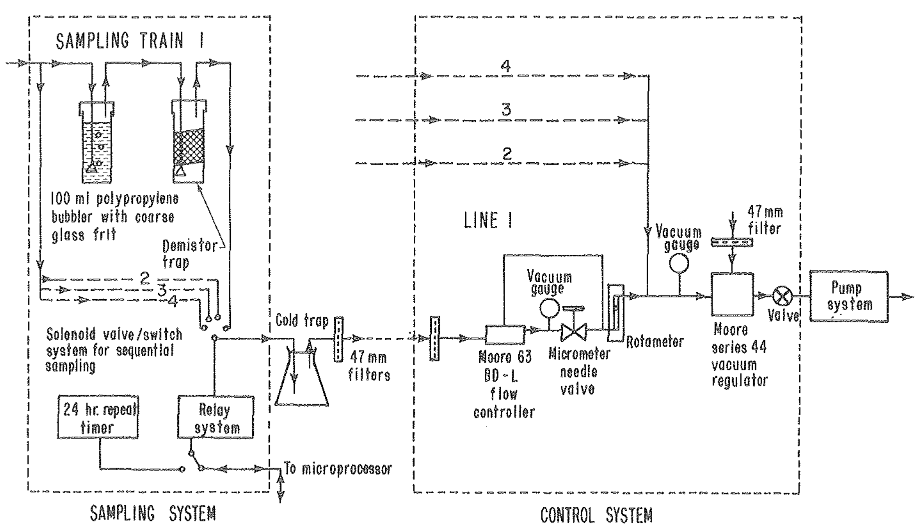


Fig. 8. Formaldehyde/aliphatic aldehydes grab sampling system. (XBL 791-257A)

The control system developed during our tests of sampling systems provides a constant and accurate air flow for sampling (better than ±3% versus ±20% using a critical orifice as recommended by government agencies). This has been achieved by utilizing a flow controller to maintain a constant pressure difference across the needle valve opening. Since a constant vacuum regulator is added downstream adjacent to the needle valve, the immediate upstream and downstream pressures of the valve are kept constant at all times. At a given temperature (the EEB Mobile Laboratory is maintained at a constant temperature), the air flow is a function of the pressure difference. Thus, the system samples air at a constant mass flow rate regardless of possible pressure changes of the bubbler and/or filter (caused by clogging, or by non-uniformity among frits, etc).

The Ventilation Program staff also has been comparing various wet chemical analytical techniques for measuring formaldehyde and total aldehydes in air. It has been determined that although they are applicable to analyses of ambient air, both the pararosaniline and chromotropic acid methods are not as sensitive as reported in the literature and are less sensitive than the MBTH method. The pararosaniline method uses toxic reagents which requires special handling. It takes considerable time (up to two hours) to develop color for spectrophotmetric measurement if the concentration of HCHO is very low. The chromotropic acid method is also difficult to work with because concentrated H_2SO_4 is required for this technique. There had been difficulty in generating a standard calibration curve (concentration of formaldehyde vs. photometric absorption) for the chromotropic acid method due to improper reagent ratios in the method described by the National Institute of Occupational Safety and Health (NIOSH);[19] this difficulty has since been resolved at LBL. Chromotropic acid (reagent grade) obtained from commercial sources need repurification to obtain proper sensitivity with this technique. Moreover, several serious interferences have been reported[20] in the chromotropic acid method. Although the chromotropic acid methods is recommended by NIOSH and various professional associations, and is therefore used widely, the method does not seem to be a good technique for measuring formaldehyde in ambient air. Although the MBTH method is sensitive and straightforward, the technique is reactive to all aliphatic aldehydes. Alternative methods such as the ion chromatographic technique and solid absorbent collection with gas chromatographic analysis are currently being studied at LBL.

Field Monitoring of Indoor Organic Contaminants

As part of the ventilation field monitoring project, total aliphatic aldehydes have been measured (as formaldehyde) at the occupied and unoccupied Minimum Energy Dwellings (MED) in Mission Viejo, California; at the Naval Regional Medical Center in Long Beach; and at the Iowa State University Energy Research House in Ames, Iowa, in 1978. Preliminary results indicate that the average concentration of aldehydes in the occupied MED house with an air exchange rate of 0.2 air changes per hour is about 65 ppb compared to 21 ppb in the unoccupied MED house and 8 ppb in outdoor air as shown in Fig. 9. The unoccupied Energy Research House in Ames has a ventilation rate of about 0.3 air changes per hour and has an average aldehyde concentration of 74 ppb compared to an average of 8 ppb outdoors shown in Fig. 10.

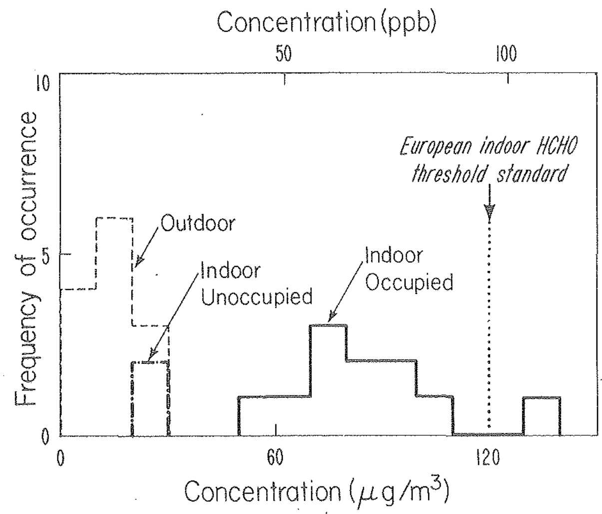


Fig. 9. Indoor/outdoor aldehyde concentrations. Minimum Energy Dwellings, Mission Viejo, California, September 1978. (XBL 796-1749)

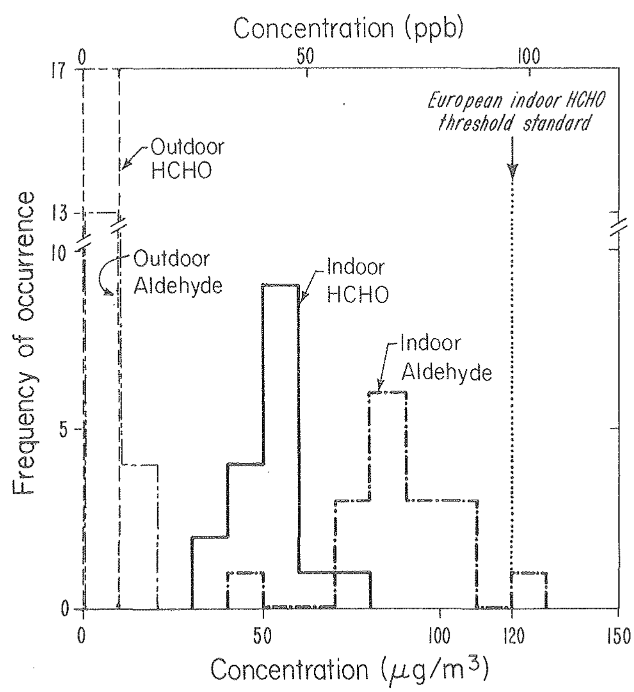


Fig. 10. Indoor/outdoor formaldehyde/aldehyde concentrations. Iowa State University Energy Research House, December 1978. (XBL 795-1488A)

From the data, it is clear that the built environment contributes to aldehyde concentrations. When combined with contributions from the occupants' activities, the indoor concentration of aldehydes sometimes exceeds recommended formaldehyde standards[18] for indoor air (100 ppb). In a well-ventilated hospital, on the other hand, no significant differences in aldehyde concentrations between indoor and outdoor air was found (see Fig. 11).

Outdoor air and indoor air collected from an LBL office trailer have also been analyzed for formaldehyde and total aldehyde concentrations. Each sample was analyzed by MBTH, pararosaniline and chromotropic acid methods. The preliminary results show that the concentrations of total aliphatic aldehydes in a 3-month old trailer (insulated with fiberglass, not urea-formaldehyde foam which is commonly used in trailers and is known to emit high amounts of formaldehyde) range from 23 to 89 ppb. Outdoor aldehyde concentrations of 1.0 to 70 ppb were substantially lower than the parallel indoor measurements. The ratio of formaldehyde (determined by both pararosaniline and chromotropic acid methods) to total aliphatic aldehydes (using the MBTH method) is 78% on average. Plywood constructed with urea-formaldehyde resin is a possible source of indoor aldehydes in the trailer.

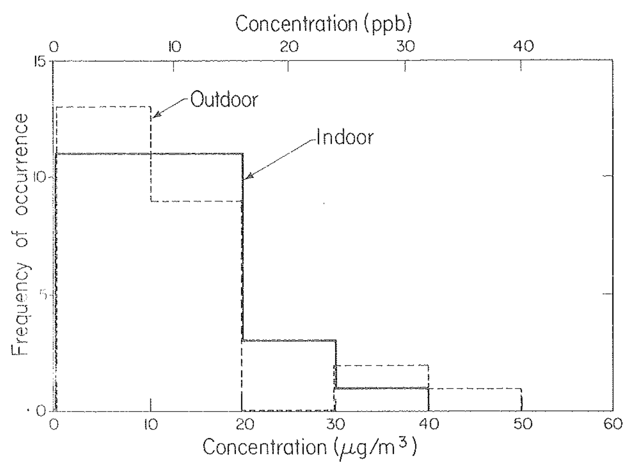


Fig. 11. Indoor/outdoor aldehyde concentration. Naval Regional Medical Center, Long Beach, California, October 1978.

(XBL 796-1747)

Planned Activities for 1979

In 1979 radon studies will continue with field monitoring of radon using the passive monitors and lab analyses of radon emissions from concrete, brick, and gypsum board. The Ventilation Program staff will continue to study various measurement techniques to develop reliable methods for determining the concentrations of formaldehyde and total aldehydes in air. Besides spectrophotometric methods, the ion chromatographic and gas chromatographic techniques will be investigated for effective quantitative analysis. This work will encompass experiments with various GC columns and solid adsorbents. Grab sampling and analytical techniques for other organic vapors will be developed. In the field, samples will be collected at residential and commercial buildings in several geographical locations in the U. S. for the analysis of formaldehyde, total aldehydes, as well as other hazardous ambient organics. In addition, an environmental chamber will be fabricated in the laboratory for the study of hazardous organics emitted from common building materials such as adhesives, sealants, paints, and wood products.

MECHANICAL VENTILATION SYSTEMS USING AIR-TO-AIR HEAT EXCHANGERS

(Roseme)

The Ventilation Program staff began a study on the use of air-to-air heat exchangers and mechanical ventilation systems for residences in October of 1978. The project consists of four parts:

- Analysis and experimental evaluation of air-to-air heat exchangers;
- Testing of a mechanical ventilation system utilizing an air-to-air heat exchanger in the EEB Walnut Creek test house;
- A cost-benefit analysis of these systems operating in different climate zones of the United States;
- Installation and testing of a number of systems in occupied homes.

About 15% of the total energy consumed in the U.S. is used for space heating and cooling in residential structures. Two major modes of heat loss or gain in a residential structure are the conduction of heat through the walls, ceilings and floors, and the natural infiltration of outside air into the structure. After a house has been reasonably well insulated, the natural infiltration of outside air into the building usually becomes the single largest mode of heat gain or loss. Houses in the United States have infiltration rates ranging from one to two air changes per hour. Homes have been built, however, in Sweden, Canada and the United States with measured air infiltration rates on the order of 0.25 air changes per hour.

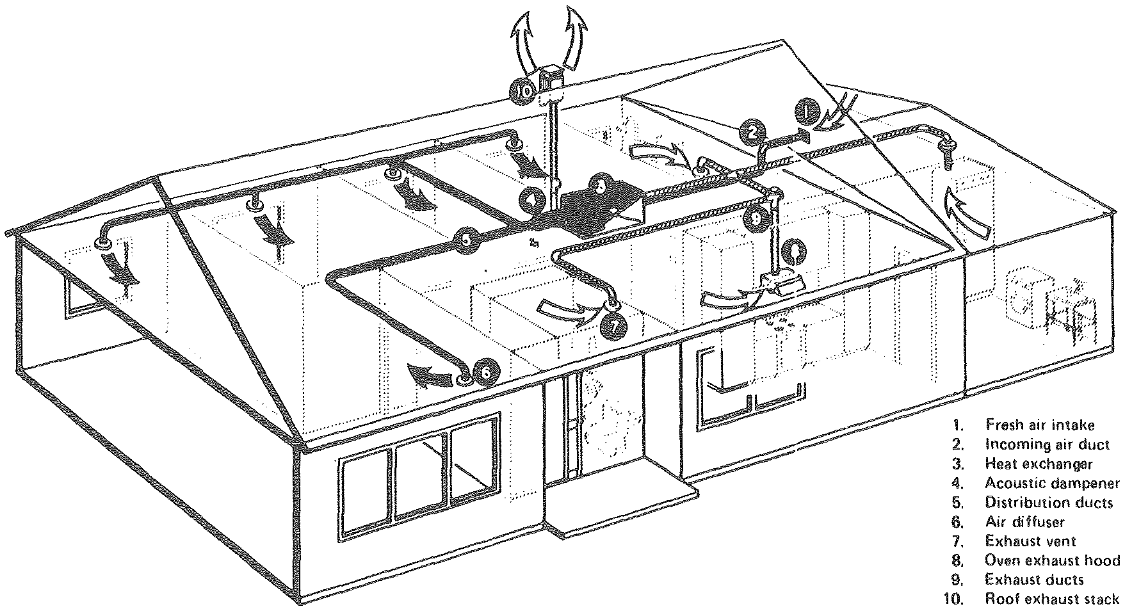


Fig. 12. Residential heat exchanger system.

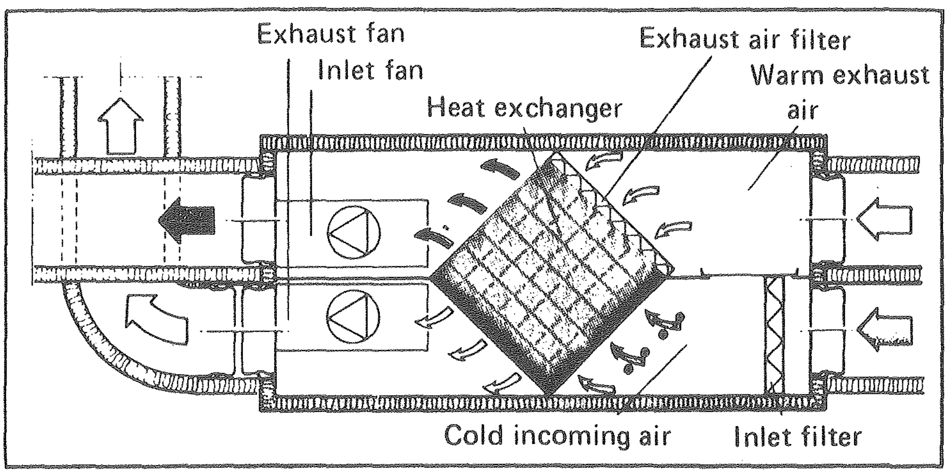


Fig. 13. Principle of operation of heat exchanger.

Many homes in the U. S. and Europe have conserved energy by reducing infiltration; however, problems associated with this reduction in ventilation have been recognized. These problems include excessive humidity levels, increased intensity of odors from human activities, and increased levels of chemical contaminants, such as formaldehyde and radon from the outgassing of building materials.

One method of alleviating these problems is to introduce a mechanical ventilation system into a nearly air-tight structure and thereby ventilate in a controlled manner when it becomes necessary. A heat exchanger or heat recovery device installed directly in the mechanical ventilation system (see Fig. 12) can save a substantial amount of energy by pre-heating or pre-cooling the incoming outdoor air. An air-to-air heat exchanger is a device that brings the incoming and exhaust air streams into close proximity so that heat can be exchanged between these streams as shown in Fig. 13.

The ramifications of a reduction in infiltration rate can be understood by examining the impact on a hypothetical house in the Chicago area during the months of December, January and February. The average temperature for these months is 26.7°F.[21] Assume a 1500 square foot house with temperature held at 68°F, unregulated humidity and a natural infiltration rate of 1.0 ach (air changes per hour). This represents a 19.27 MBTU uncontrolled ventilation load on the heating system for the three months. If the natural infiltration were reduced from 1.0 to 0.25 ach, the ventilation load would be reduced to 4.82 MBTU, a reduction of 75%. The problem, however, is that while infiltration has been significantly reduced and energy savings achieved, air quality has probably deteriorated. In several energy conservation houses, there have been reports of very high internal humidity levels, causing mold to grow on the walls. In Sweden, where low natural infiltration rates are mandated by law, there have been significant problems with the outgassing of formaldehyde from particleboard used in construction. Installation of a mechanical ventilation system with a heat exchanger in a nearly air-tight structure, however, would provide sufficient ventilation (thus assuring good air quality).

A mechanical ventilation system is a combination of electric fans and duct work designed to provide controlled ventilation air whenever necessary. This is in direct contrast to uncontrolled natural ventilation. The inclusion of a heat exchanger between the incoming and outgoing air streams can save over half of the heat that otherwise would have been lost in the exhaust air.

If the homeowner in Chicago were to install a mechanical ventilation system utilizing an air-to-air heat exchanger with a 60% temperature efficiency and operate it so that it provides 1 ach for 12 hours per day, the total ventilation load (including two 1/6 HP fans) would be 9.6 MBTU. This would represent a 50% reduction in the ventilation load. If the ventilation load for the house in Chicago were half of the total heating load for the house, then the installation of a mechanical system with a heat exchanger would reduce overall heating load requirements by 25%. This reduction over the 3 month period would save the Chicago homeowner $31.11 in natural gas costs (at $2.26/MBTU and 70% furnace efficiency), or $127 in electricity costs (at 4.5 ¢/Kwh). Additional savings could be realized at all other times when heating/cooling is required.

A theoretical analysis of commercially-available air-to-air heat exchangers in various modes of operation is being performed by the Mechanical Engineering Department at the University of California in Berkeley, under sub-contract to LBL. In addition, LBL is building a facility for testing commercially-available residential model air-to-air heat exchangers.

Planned Activities for 1979

A prototype mechanical ventilation system utilizing an air-to-air heat exchanger is to be installed in the EEB Walnut Creek test house. Efficiency measurements and indoor air quality tests will be performed.

A request for proposals (RFP) will be issued in the spring of 1979, for a study to install and evaluate residential mechanical ventilation systems with heat recovery devices in several residential houses in a region of the United States that has extreme summer and winter weather conditions. Energy savings, indoor air quality and different modes of operation are to be tested.

The heat exchanger performance data generated by this project will be combined with appropriate climatological and economic parameters, in order to develop an economic model evaluating life-cycle costs of heat exchanger utilization in single family dwellings. Results will be assessed against baseline data from "typical" single family dwellings in the same environment. Returns on investment and payback periods will be estimated for various commercial heat exchangers operating in different environments.

SUBCONTRACT ACTIVITIES

(Turiel)

In addition to activities conducted by the Naval Biosciences Laboratory (previously discussed) and the University of Minnesota (see Hospitals Program), the Ventilation Program's technical management group has been directing three other major subcontracts:

- Assessment of ventilation requirements for odor control;
- Review of ventilation regulations and enforcement practices; and
- Development of automatic variable ventilation control systems.

Odor Control

The John Pierce Foundation of Connecticut, in collaboration with The Research Corporation of New England (TRC), is in the process of conducting a review of existing regulations for odor control in buildings and their underlying data base. It appears that the minimum ventilation rates established by various state and local governments for institutional and commercial buildings are based on research performed by C. P. Yaglou over forty years ago.[22,23] He determined that for sedentary adults under "normal" conditions, approximately five cubic feet per minute per occupant of outside air is the minimum amount required for odor control in buildings. It is important to note that these studies were conducted under laboratory conditions and not in actual buildings. There have been few research studies[24,25] measuring odors at locations where odor levels are relatively low. Most studies have been concerned with severe industrial-type odor problems.

Work on the odors project has been divided into two phases. Phase I, begun in 1978 by the John Pierce Foundation, consists of a literature survey of:

1) Existing and proposed ventilation requirements for odor control in buildings;

2) Odor measurement techniques, both analytical and subjective; and

3) Air treatment systems for odor control in institutional and commercial buildings.

In a second, related task, John Pierce has begun conducting a critical review of the existing data base in order to make specific research recommendations designed to fill the gaps in this data base.

Planned Activities for 1979

Phase II of the odors subcontract research is scheduled to take place in 1979 and 1980. It will combine both laboratory and field based investigations of ventilation requirements for odor control in buildings. Both subjective questionnaires and psychophysical[26] testing techniques will be used in the laboratory and field experiments.

We are seeking data on the perceived odor intensity as a function of several variables. Included among these variables are total mechanical ventilation rate, percent recirculation, infiltation rate, filtration and masking techniques, environmental variables and room occupancy variables.

The environmental and room occupancy variables of interest include:

1. Room volume
2. Number of occupants
3. Activity in room
4. Personal hygiene of occupants
5. Temperature
6. Relative humidity
7. Air movement in room
8. Quality of outside air

The Phase II work, to be performed by both the John Pierce Foundation and TRC, is outlined below in sequential steps:

Task 1: Select measurement techniques and adapt them for odor evaluation in buildings

Task 2: Conduct a field study of odors and their sources in the following types of buildings:
  a. Educational facilities
  b. Hospitals

Task 3: Perform field-based perceptual and behavioral studies in the buildings identified above and accompany these by laboratory-type odor intensity and threshold measurements.

Task 4: Perform air quality characterization (analytical) of odors on samples taken during Task 3.

Task 5: Recommend ventilation requirements and modifications in the HVAC systems for odor control in institutional and commercial buildings.

Task 6: On the basis of Phase I work, propose air treatment systems for odor control in institutional and commercial buildings and conduct cost-benefit analyses which include energy considerations.

The ultimate objective of the odors project is to determine the minimum ventilation air quantities needed for human health, comfort, and productivity. Ultimately, it is hoped that the state of current knowledge on odor intensity and perception can be expanded sufficiently so that ventilation standards for odor control in institutional and commercial buildings may be recommended and eventually codified by the appropriate governmental entities.

Review of Ventilation Regulation and Enforcement Practices

Melvyn Green & Associates, Inc., conducted a field survey of current practices in the enforcement of ventilation regulations. Minimum ventilation rates are specified in the various building codes adopted by state and local governments. On a national level, there are three principal model codes (from which local codes are often derived): the Uniform Building Code (UBC), the Basic Code (BOCA), and the Standard Code (SBCC).

Building codes are enforced by both a review of plans submitted for obtaining a building permit and by on-site inspection. The building department is usually a local governmental agency, although sometimes it is under state jurisdiction. Plan checkers are often licensed engineers or architects, whereas inspectors typically have experience in the construction trades.

Interviews were conducted in four states--California, Maryland, Ohio, and North Carolina--in order to obtain a cross-section of environmental conditions, as well as principal types of building regulations.

From an analysis of responses to the questionnaires, the following conclusions emerged:

1) Most mechanical plan checking and inspection emphasize only safety rather than both health and safety criteria;

2) Many building inspectors and checkers do not have the authority to enforce technical regulations for energy conservation;

3) Increased checking for energy requirements, including ventilation, is causing delays and cost increases in construction.

Some of the recommendations proposed to alleviate these problems are:

1) More practical training needs to be made available to building department staff to improve building code implementation;

2) Public recognition of ventilation as a health issue should be promoted;

3) Instructions for the enforcement of ventilation regulations need to be developed.

Automatic Variable Ventilation Control Systems

At present, mechanical ventilation systems usually provide a fixed quantity of "fresh" air to a building space based upon the maximum number of people expected to occupy that particular space. When the use of a building space is below its design maximum, the amount of outside air brought into the space can be reduced, thus reducing energy consumption through lower heating and cooling loads. One method of determining the necessary ventilation rate for a particular space is to utilize an air quality detector (e.g., CO, CO_2, O_2) sensitive to building occupancy and activity load. The output of the detector can, in turn, be used to control ventilation rates. Before the control system can be implemented, however, it is necessary to determine the relationship between the detected air quality parameter and the required ventilation rate in an occupied space. Efforts will soon be underway to estimate the cost-effectiveness of such variable ventilation control systems and to assess their marketability, both now and in the future. In response to an RFP, eight proposals for development of automatic variable ventilation control systems, based on air quality, are being reviewed. In general terms, the scope of work to be carried out in 1979 and 1980 is as follows:

1) Establishment of the relationships between building air quality, occupant/activity loads, ventilation rate, and ventilation health and comfort requirements.

2) Design, fabrication and test of a variable ventilation control system with air quality sensors in one or more demonstration buildings. (It is expected the initial demonstration sites will be in educational facilities.)

3) Determination of the cost-effectiveness of variable ventilation control systems with air quality sensors for specific building types and for specific mechanical ventilation systems within these building types.

4) Evaluation of the effectiveness of the demonstration phase of the program and provision of an estimate of the magnitude of the energy savings expected through national implementation of automatic variable ventilation control systems based on building air quality.

5) Assessment of: current and future markets for the proposed automatic variable ventilation control system based on occupancy sensors; types of buildings in which these systems can be used; type of mechanical ventilation systems appropriate for automatic controls; and market penetration potential in these various types of buildings. Assessments will include consideration of both new and existing buildings.

VENTILATION DATA BASE

(Langenborg, Hillis, Nyberg)

The Lawrence Berkeley Laboratory, in conjunction with the Department of Energy, is involved in the development of a computerized data base focusing on building ventilation and indoor air quality research. Largely in response to the increasing importance of national energy conservation, considerable research effort is being directed toward the areas of building ventilation and indoor air quality. These fields are expanding so rapidly that normal information transfer channels, both within the scientific community and the general public, were considered inadequate. Information transfer to the public sector will be streamlined by the introduction of a computerized information system. The data base, focusing on ventilation and indoor air quality literature, will be directly accessible via telephone lines and a high-speed computer network link. Reports and data abstracts produced by the LBL Ventilation Program will be added to the system in order to facilitate availability to technical and non-technical personnel.

The ventilation data base, when fully operational, will consist of fourteen resource modules:

1) Available resources
2) Bibliography
3) News
4) Seminars, workshop, and conferences
5) Who's Who in ventilation
6) Ventilation--research and development projects
7) Ventilation--business and finance
8) Ventilation--standards and guidelines
9) Models
10) Analysis
11) User alert service
12) Hard copy output
13) Utility routines
14) Help

Two basic functions of these modules are to aid the user in bibliographic information retrieval (module 2) and to offer a variety of information dissemination services. Basic user access will be via an interactive session with the data base, where English language instructions will be given in the phases of data selection, processing and display. User support will be available through the utility routines, help, and user alert service modules.

Since the bibliographic module spans a diverse range of technical disciplines, assistance was needed in conducting the initial literature survey. To aid in this capacity, and also to take advantage of existing expertise, LBL engaged subcontractors to conduct selective literature searches in the ventilation/indoor air quality field. Implementation of the survey was accomplished through standard retrieval procedures, including computerized literature searches. The references obtained through searches were evaluated and pertinent citations were manually compiled. When an abstract was not available, the article itself was retrieved and an abstract written. Keyword descriptors, used in the indexing process, were next assigned to each citation. These descriptors reflect an article's content and form a controlled vocabulary of precise words relating to the ventilation field. The resulting bibliography consists of citations, abstracts and keywords relating to relevant domestic and foreign literature, both published and unpublished.

The scope of the initial literature surveys completed by LBL and subcontractors was delegated as follows:

Area	Organization
Contamination control	LBL
Infiltration	LBL
Radon	LBL
Odor Control	John B. Pierce Foundation of Conn., Inc.
Air hygiene in buildings	Naval Biosciences Laboratory
Hospital energy conservation and ventilation requirements	University of Minnesota

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 survey of infiltration literature 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 examined.

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.

The Naval Biosciences Laboratory has surveyed the literature on sampling, transmissions, and control of airborne biological contaminants in enclosed spaces.

In the area of hospital energy conservation, emphasis is placed on the patient environment, with respect to heating, ventilating, and air conditioning parameters. Topics include 1) general air hygiene, hospital-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. Related subject areas include airborne contaminants related to HVAC systems, energy recovery technology, and alternative hospital HVAC system configurations.

Data access algorithms currently being written require the management system to support a single controlled vocabulary able to index any bibliographic citation maintained in the data base.

A noteworthy feature of the data base is the organization of the controlled vocabulary (keywords) into a set of loose tree structures in which logical relationships will be reflected whenever possible. These tree structures will reflect conceptual groupings within a field of interest and will provide the user with the option of surveying the entire vocabulary through either an alphabetical listing or a logical listing, surveying a logical sub-section of the vocabulary, or interactively stepping through the vocabulary and selecting the appropriate keywords. The purpose of the organizational strategy is twofold:

1) It may expand the user's knowledge. A single keyword match made by the user may reveal other keywords of interest.

2) It will quickly indicate keyword coding strategies used in the data base so that the user will not be forced to "outguess" the original abstractors.

Keywords presented to the user differ primarily in how they will be utilized in search algorithms. They are classified as either self-explanatory keywords or keywords linked to an explanatory scope note. Self-explanatory keywords will be a simple string of characters. That exact literal string will be displayed to the user, confirmed, and routed to the pattern matching search routines. Keywords linked to a definitional scope note will be displayed to the user accompanied by their scope note. The additional information from the scope note should aid the user in determining the applicability of the keyword. The scope note itself, however, is ignored in pattern matching. After user confirmation, the keyword will be treated as a self-explanatory keyword by the search routines. Synonyms, plurals, and variants will be mapped into the controlled vocabulary. An illegal synonym and its valid vocabulary counterpart will be displayed to the user, at which point the controlled vocabulary keyword may either be accepted or rejected. Unknown words will be echoed as such.

Information dissemination services available through the data base will provide the user with current awareness information. The information available in modules 4 through 6, conveniently obtainable from a single source, may be of special interest to data base users. "Seminars, Workshops, and Conferences" (module 4) will provide a calendar of events relevant to ventilation. "Who's Who in Ventilation" (module 5) will enable the user to obtain an alphabetical listing of individuals interested in ventilation and indoor air quality research. If a more specific listing is desired, search parameters such as name, affiliation, or main field of interest may be designated. A listing of "Ventilation Research and Development Projects" (module 6) is to include both foreign and domestic projects and will, in addition, flag DOE-sponsored projects.

Remote user access to the data base will be available by direct dial telephone lines to a PDP-11/70 computer housed at LBL or via a high-speed link to the ARPANET computer network.

The data base will be supported on the PDP11-70 by the UNIX operating system and the INGRES data base management system. The ventilation data base, rather than being developed using assembly language, relies heavily on existing support programs provided by UNIX and INGRES, thereby greatly reducing implementation time while adding flexibility and clarity to the data base programs. INGRES is used to execute low-level search and retrieval routines for the data base, and thus implicitly has established the internal data structures.

User interface routines are currently being implemented in the programming language "C" and in the system calls to UNIX. These programs will initiate a user-friendly dialogue and translate user commands into appropriate INGRES and/or UNIX directives. The intent is to minimize the "learning time" necessary to use the resources of the data base.

In short, the scope of the ventilation data base project in 1979 is to establish a prototype data base offering a variety of services in a user-friendly environment. Emphasis is being placed on developing rather complete data structures. Once the data base is opened to the public, major data elements will be monitored and expanded or reduced as indicated by actual user demand. Future development will offer improved human-dialog software and information categories that are continually tuned to user needs.

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Indoor Air Quality: Gas Stove Emissions

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INTRODUCTION

Air pollution research has recently begun to focus on the problem of indoor air quality. Several studies have shown that the concentrations of some pollutants in residential buildings frequently exceeds those levels commonly occurring in the outdoor environment.[1-6] Chemical and biological contaminants released into indoor environments are undesirable but often unavoidable byproducts of human activity. Typical indoor contaminants include gaseous and particulate pollutants from indoor combustion processes (e.g., cooking, heating, cigarette smoking), toxic chemicals and odors from cooking and cleaning activities, odors and viable microorganisms from humans, and odor-masking chemicals used in several activities. In addition, a wide assortment of substances known to be potentially hazardous (e.g., asbestos, radon, formaldehyde, vinyl chloride) are released from indoor construction materials and furnishings.

Reduced infiltration and ventilation rates in buildings, proposed as important energy conservation measures, can lead to elevated levels of indoor-generated air contaminants. When contaminant concentrations reach excessively high levels, they may impair the health, safety, and/or comfort of the occupants.

Many studies have attempted to correlate air quality with both morbidity and mortality rates. The conclusions of such epidemiological studies are in serious doubt since they relied on outdoor air quality data only. Since most people spend 80% of their time indoor, outside air is not totally representative of the air people normally breathe. Another problem is that most such studies have concentrated on only a few gaseous pollutants (principally CO, O_3, SO_2, NO_x) and have ignored other important pollutants, especially the respirable fraction of particulates. If any such study is to succeed, the indoor pollutants must be characterized and traced from the point of origin to the receptor (population group under study). Only then can the quality of the air that is actually inhaled by the sample population be indexed in a manner that is both scientifically valid and applicable to large populations. Currently, a major effort is underway to develop models to assess the total exposure of the human population to various harmful pollutants. In order to do this, indoor air quality must be characterized and modeled for a variety of indoor environments. Factors such as pollutant emission rates from indoor sources and air exchange rates of buildings are very important in such modeling efforts.

This project critically analyzes the role of indoor combustion appliances and their impact on indoor air quality in residential buildings. Gas stoves pose the greatest problem since they are usually vented directly into the kitchen, unlike most furnaces or water heaters which are vented to the outdoors. Although range hoods could alleviate some of the problems if installed, they are rarely used due in large part to the high noise levels associated with them.

Most studies have assumed that indoor air pollution occurs as a direct result of outdoor sources. Such studies have been concerned mainly with SO_2, CO, O_3 or total suspended particulate matter. Surprisingly little work has been directed toward analyzing other potentially important indoor air pollutant species, such as NO, NO_2, nitrates, sulfates, metals, organics, and the respirable fraction of particulate matter. Although emission of CO from gas stoves and heating systems has been extensively investigated, other emissions from indoor combustion sources have not been thoroughly studied. It is known that combustion processes can yield a wide variety of different and potentially hazardous substances, including aldehydes, nitrogen-containing compounds[7] (e.g., nitrogen oxides, hydrogen cyanide, ammonia) and respirable particulates. There is evidence that interactions between primary combustion products result in the production of secondary species. For example, it has been shown that gaseous nitrogen compounds can rapidly undergo catalytic oxidation or reduction to other important air pollution species such as nitrates, nitric acid, ammonium, and other organic nitrogen compounds of the amino and pyrimidine type.[8]

The significance of indoor air pollution--only recently recognized--is now expected to have a large impact on (1) the overall assessment of the effect of air pollution on human health, (2) the design of epidemiological studies that must consider indoor as well as outdoor air pollution, (3) energy conservation strategies for buildings that might restrict indoor-outdoor air exchange, and (4) the need for more stringent control of air pollution from indoor combustion sources.

The work reported here represents the accomplishments of the ongoing laboratory studies which systematically examine gaseous and particulate air pollutants in residential buildings. The measurement techniques used in the field and laboratory experiments have been previously described.[3-4]

GASEOUS EMISSIONS: NITROGEN DIOXIDE, CARBON MONOXIDE, ALDEHYDES AND HYDROGEN CYANIDE

Our early field studies have shown that levels of CO and NO_2 approach or exceed existing U. S. ambient outside air quality standards in some residential buildings with gas appliances.[3] Nitrogen dioxide levels in kitchens of houses with gas stoves were observed to be as high as 0.5 ppm when one top burner was operated for less than 30 minutes and as high as 0.8 ppm when the oven operated for 20 minutes. Concentrations of NO_2 were observed to be as high as 0.6 ppm for eight hours in the bedroom of a house with a forced-air gas-fired heating system operating under normal conditions. These NO_2 concentrations can be compared with the short-term U. S. and foreign NO_2 ambient outside air quality standards shown in Table 1 (approximately 0.2 ppm for 1 hour).[9-12]

Table 1. Recommended and promulgated short-term NO_2 air quality standards.[9-12]

County	Short-Term NO_2 Air Quality Standard (0.1 ppm ≈ 190 μg/m^3)	Status
Canada	0.2 ppm/1 hr	promulgated
(Ontario)	0.2 ppm/24 hr	promulgated
Japan	0.04-0.06 ppm/24 hr	promulgated
U.S.A.	0.25-0.50 ppm/hr	recommended
West Germany	0.15 ppm/short-term exposure	promulgated
WHO/UNEP	0.10-0.17 ppm/hr	recommended

Studies using an experimental room with a volume of 950 ft^3 (27 m^3) have characterized the emissions from a new gas stove operating in the room with air exchange rates ranging from 0.25 to 10 air changes per hour (ach).[13] These laboratory studies have shown that gas stoves generate extremely high emissions of such species as CO, NO, NO_2, and respirable aerosols (size <2.5 μm), and that the concentration of these species becomes significant when the air exchange rate is controlled to less than 1 ach. We have observed that the CO concentration exceeds the 1-hour ambient outside air quality standards only under "tight" conditions (0.25 ach), but the NO_2 concentration exceeds the recommended 1-hour standard, even with an air exchange rate as high as 2.5 ach. Table 2 gives the 1-hour average NO_2 concentrations in the experimental room. Particularly noteworthy is the observation that a kitchen ventilation rate of 50 cfm (the upper limit of the recommended ASHRAE Standard 62-73 ventilation rate for residential kitchens)[14] results in a 1 hour average NO_2 concentration of 0.4 ppm, a value considerably higher than the promulgated foreign standards. Lower ventilation rates result in even higher NO_2 concentrations.

Aldehyde emissions were also found to be significant. Total aldehyde levels reached a half-hour average of 670 μg/m^3 (0.56 ppm as formaldehyde) under "tight" conditions (0.25 ach) when using two burners for 16 minutes. Similar levels of aldehydes were observed when the oven was operated for 1 hour at 350°F; the peak half-hour concentration was 760 μg/m^3 (0.62 ppm as formaldehyde). It is very likely that formaldehyde constitutes most, if not all, of the aldehydes produced by the gas stove. In view of the present concerns about formmaldehyde and its adverse health effects, these high concentrations of aldehydes are particularly significant.

Table 2. Nitrogen dioxide concentrations in a test kitchen.

Air Exchange Rate in Kitchen	NO_2 in Kitchen*
0.25 ach (No stove vent)	1.2 ppm
1.0 ach (With hood vent above stove)	0.80 ppm
2.5 ach (Stove hood vent with fan at 50 CFM)	0.40 ppm
7.0 ach (Stove hood vent with fan at 140 CFM)	0.10 ppm
Outside during test	0.03 ppm

*(1-hour average concentration in kitchen with a gas oven on for 1 hour at 350°F).

Typical ambient outside NO_2 concentrations	:	0.02 ppm (clean)--0.30 ppm (heavy pollution)
Promulgated and recommended 1-hour NO_2 standards	:	0.20-0.40 ppm
ASHRAE ventilation requirements for kitchens in single family residential houses	:	Recommended: 30-50 CFM (ASHRAE 62-73) Minimum: 20 CFM (ASHRAE 90-75)

As a component of indoor air, formaldehyde has received considerable attention primarily because of formaldehyde outgassing from building materials such as particle-board and urea-formaldehyde foam insulation. It is apparent that it can also result from combustion processes. Formaldehyde has a pungent and characteristic odor which can be detected by most people at levels well below 1 ppm. The toxicity of formaldehyde is apparent when it comes in contact with the skin or mucous membrane; exposure to formaldehyde can cause burning of the eyes, weeping, and irritation of the upper respiratory passages. High concentrations (above a few ppm) may produce coughing, constriction in the chest, and a sense of pressure in the head. Several studies reported in the literature indicate that swelling of the mucous membrane begins in the range of 0.05 and 0.1 ppm, depending on the individual sensitivity and environmental conditions (temperature, humidity, etc.). Review of the disease effects of formaldehyde are given in a recent EPA report,[15] work reported in Denmark,[16] and recent studies carried out in Sweden.[17,18] Various recommended and promulgated formaldehyde air quality standards are given in Table 3. European countries are moving rapidly to establish formaldehyde standards. In July, 1978, the Netherlands established a standard of 0.1 ppm (120 μg/m^3) as the maximum permissible concentration.[19] Denmark, Sweden, and West Germany are all considering establishing a standard at approximately the same value (0.1 ppm).

The aldehyde levels measured in our experiments greatly exceed these European standards, as well as the recommended ambient outdoor standards for this country. Even at higher air exchange rates, it appears that the stove will generate concentrations in excess of these standards. It is our assumption that formaldehyde constitutes most of the aldehydes emitted by the stove; studies to measure formaldehyde with a specific colorimetric test are now in progress to confirm this hypothesis.

Hydrogen cyanide (HCN) was detected but only at very low levels. When the oven was on for 1 hour at 350°F, under tight conditions (0.25 ach), hydrogen cyanide concentrations reached a half--hour average of 90 μg/m^3 (0.08 ppm). This is well below the OSHA standard of 10 ppm, measured as an 8-hour time weighted average.[23] The

Table 3. Recommended and promulgated formaldehyde air quality standards.

Country	HCHO standard (0.1 ppm 120 μg/m^3)	Status
AMBIENT AIR		
U.S.A.	0.1 ppm maximum	recommended[20]
INDOOR AIR		
Denmark	0.12 ppm maximum	recommended[16]
The Netherlands	0.1 ppm maximum	promulgated[19]
Sweden	0.1-0.7 ppm maximum	recommended[17,18]
West Germany	0.1 ppm maximum	recommended[21]
OCCUPATIONAL AIR		
Denmark	1 ppm TLV*	promulgated[22]
U.S.A.	3 ppm TWA	promulgated[23] (OSHA)
	2 ppm TLV*	promulgated[24] (ACGIH)
	2 ppm/30 min	recommended[25] (NIOSH)
West Germany	1 ppm TLV*	promulgated[22]

TWA = 8 hours time weighted average.

*TLV = Threshold limit value.

low concentrations observed indicate that, in spite of its well-known toxicity, hydrogen cyanide constitutes a relatively minor health hazard, at least, in comparison with other emitted compounds.

Measured emission rates for several gaseous species from gas stove overs and top burners are shown in Tables 4 and 5. The values from this study are compared with results from other works. Total aldehydes were measured using the MBTH (3-methyl-2- benzothiazolone hydrazone) method.[29] Samples were collected by bubbling air through a solution of MBTH in an ice bath; under these conditions, the collection efficiency is approximately 91%. After collection in the bubbler, an oxidizing solution consisting of ferric chloride and sulfamic acid was added to each sample. The intensity of the green color which formed is proportional to the concentration of aldehydes present.

Hydrogen cyanide was measured using an ion-selective electrode.[30] Samples were collected by bubbling air through a solution of sodium hydroxide in an ice bath. The hydroxide traps nearly 100% of the HCN by converting it to cyanide ion; in this form, it can be analyzed with an

Table 4. Gas stove oven emission rates (μg/Kcal).

Pollutant	Lawrence Berkeley Laboratory	The Research[26] Corporation of New England (TRC)		British[27] Gas Corporation	American[28] Gas Association Standard
	Oven at 350°F	Old Stove Oven (Steady State)	New Stove Oven (Steady State)	Oven (General)	
CO	600-1300	530	1620		645
NO	20-50	91.4	77.9	} 85 (NO + NO_2)	
NO_2	30-60	73.1	50.4		
SO_2	0.5-1.0				
HCN	1.8				
Aldehydes	16				
Kcal/hr	2000	2200	2200		

Table 5. Gas stove burners emission rates (μg/Kcal)*

Pollutant	Lawrence Berkeley Laboratory	British[27] Gas Corporation	American[28] Gas Association Standard
Gaseous Emissions			
CO	720		645
NO	47	} 136 (NO + NO_2)	
NO_2	78		
SO_2	0.85		
HCN	0.7		
Aldehydes	21		
Particulate Emissions (Respirable Fraction)			
Carbon	0.9		
Sulfur (as $SO_4^=$)	0.04 (0-0.08)		
Total Respirable Mass	1.5(1.0-2.6)		
Kcal/hr burner	2500		

*Operated with water-filled cooking pots.

ion-selective electrode. In this device, similar to a pH meter, the voltage between a special cyanide-sensitive electrode and reference electrode is measured. By comparison of this voltage with that arising from a solution of known cyanide content, the cyanide content of the solution (and hence that of the air sample) can be determined.

PARTICULATE EMISSIONS

In 1978, a major effort was undertaken to characterize particulate emissions from gas stoves. The particulates were characterized for both size and chemical composition. Chemical composition measurements were made by collecting size-segregated aerosols on various filter substrates for subsequent laboratory analysis. It was necessary to segregate the samples by size in order to examine the respirable fraction of particulate matter. Aerosols collected on teflon filters were analyzed for mass (gravimetrically) and an array of elements (S, Pb, Ca, Fe, etc.) using X-ray fluorescence techniques. Aerosols were also collected on quartz filters to measure total carbon using a combustion technique. Aerosol size measurements were performed by a commercial electrical mobility analyzer.

Particulates are deposited in different parts of the respiratory tract, depending on their size (see Fig. 1). Particulates which pose the greatest health hazard are those with diameters

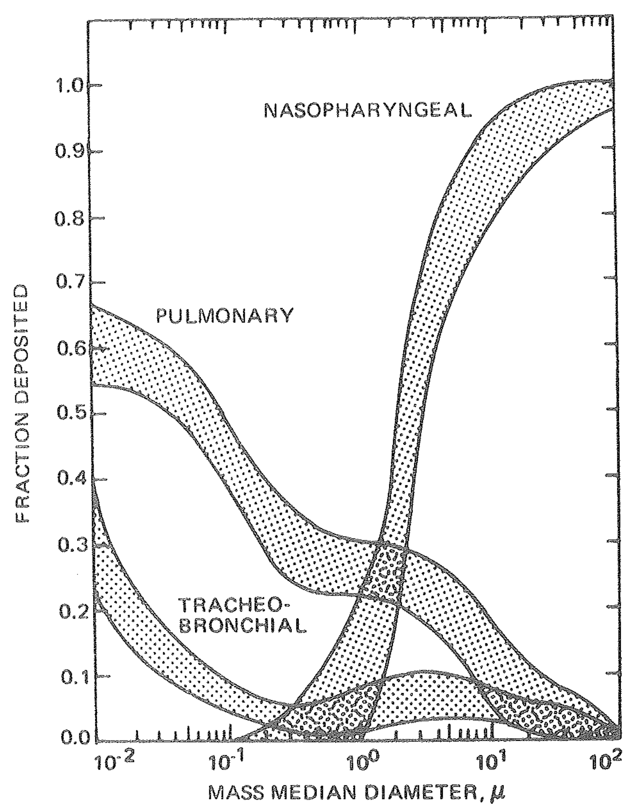

Fig. 1. Fraction of particles deposited in the three respiratory tract compartments as a function of particle diameter.[31] (XBL 771-7190)

less than 0.5 microns. The very fine particulates can travel as far as the alveoli where removal mechanisms are slower than in other parts of the respiratory system. Once in the alveoli region, the particulates exert a toxic effect on the individual through various biological mechanisms.[31]

Figure 2 summarizes the size characterization of gas stove particulate emissions. Figures 2A and 2B show the particulate size distribution in experiments with two burners operating for 15 minutes. These experiments were conducted in the experimental room described previously. In both cases (Figs. 2A and 2B) an initial combustion emission peak near 0.025 microns was observed, but within minutes, the majority of particulates increased in size to a mode between 0.05 and 0.5 microns. These are the same particulates that pose the greatest harm to human health. For comparison, Fig. 2C shows particulate size distribution at the peak of an air pollution episode in the San Francisco Bay Area. It can be seen that burners of a gas stove generate large numbers of very small particulates that approach or exceed fine particulate levels on a very smoggy day.

Particulates were analyzed for chemical composition to account for all the mass emitted in experiments under similar conditions. Carbon was observed to be a major component of the particulate emissions from the gas stove. Its emission rate was constant in all burner experiments. The total mass emission rate of respirable particulates varied, however. In some cases (see Fig. 2B), 90% of the total mass was measured to be carbon. In other cases (see Fig. 2A), the mass of emitted respirable particulates was found to be 2 or 3 times the mass of carbon emissions. Thus, while all experiments were conducted under the same conditions, the stove generated a variable fraction of particulate mass which has not yet been identified. Sulfate (measured as particulate sulfur) was found to account for less than 10% of the unidentified mass.

Future laboratory studies will investigate the possibility that various particulate nitrogen-containing compounds contribute to the total mass emissions. One hypothesis is that carbon particles act as catalysts with gas phase compounds for secondary particulate formation. This catalytic behavior may vary as a function of several variables including temperature, humidity, air exchange rate, and background air composition. Studies in progress are testing this hypothesis.

Although use of the gas oven contributes significantly to the production of gaseous species, its contribution to the production of particulate species is relatively negligible compared to the amount of particulates generated by the burners. Particulates generated by oven use must traverse a constricted path before entering the kitchen environment. The particulates most likely coagulate very quickly and deposit on the inner surfaces of the stove. The emission rate of oven particulates into the kitchen en-

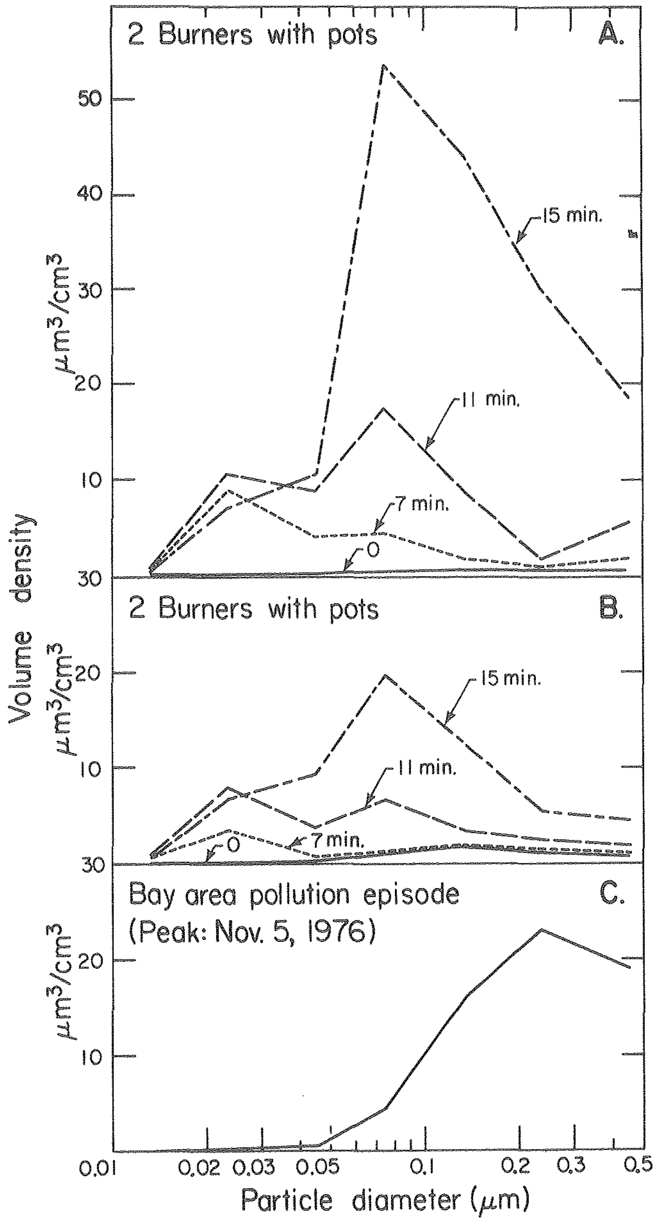

Fig. 2. Volume density and distribution of particulate emissions less than 0.5 μm in diameter. Figures 2A and 2B illustrate gas stove particulate emissions for two experiments under similar conditions in which two top burners were operated with water-filled cooking pots. The size distribution at 7, 11 and 15 minutes after turning on the burners is shown. Figure 2A shows the case where carbon accounts for 35% of the total emitted mass. Figure 2B shows the case where carbon accounts for 90% of the total emitted mass. In both cases, the absolute amount of carbon emissted is the same. Figure 2C shows the peak volume concentration distribution for a San Francisco Bay Area air pollution episode.
(XBL 791-235A)

vironment is an order of magnitude less than that of the burners, which inject particulates directly into the kitchen. Particulate emission rates from the burners are reported in Table 5, along with corresponding gaseous emission rates.

CONCLUSIONS

The field and laboratory measurements carried out thus far indicate that combustion-generated indoor air pollution may have a significant impact on human health. This study has demonstrated that elevated levels of gaseous air pollutants (CO, NO, NO_2 and aldehydes) and respirable particulate carbon and sulfur compounds are present in indoor environments where gas appliances are used. Observed levels of CO, NO_2 and aldehydes approach or exceed promulgated and proposed ambient air quality standards. Observed levels of respirable particulate mass are comparable to those present on a very smoggy day. Such levels are unacceptable for the indoor environment and are likely to limit effective implementation of energy conservation measures in residential buildings, unless other methods for ventilating air are built into energy-efficient buildings.

Indoor pollution levels are strongly affected by human activities in a building; by the manner in which building materials are incorporated into the structure; and by other aspects of the building's design, particularly the infiltration or ventilation rate. LBL is studying two design features that may be introduced to limit increases in pollution levels:

(1) Mechanical ventilation systems could be coupled with an air-to-air heat exchanger to transfer heat (and not contaminated air) from the exhaust to the fresh air stream in winter and vice versa in summer. Already in use in larger buildings, small heat exchangers (50-500 cfm) are now being marketed for homes in Europe and Japan. These could be used to maintain air exchange rates and control contaminant concentrations at acceptable levels, while reducing heat losses from air exchange.

(2) indoor air could be circulated through contaminant control devices (e.g., electrostatic precipitators, particle filters, chemical adsorbents) thus substantially reducing the concentration of particulate and gaseous contaminants.

PLANNED ACTIVITIES FOR 1979

Laboratory investigations of particulate and gaseous emissions from gas stoves will continue. The primary emphasis will be to characterize further the composition of the particulates and to determine why the respirable mass emission rate varies so widely. Nitrogen-containing compounds will be the first to be investigated in this respect.

In 1979, LBL will return to the field to assess the actual impact of combuston appliances in residential buildings. The problem of pollutant dispersion throughout a residential building is particularly important. For future epidemiological studies, it is important to know whether the observed elevated contaminant levels are restricted to the kitchen area or whether they cause elevated levels throughout the house, thus making the 8-hour sleeping period crucial in epidemiological considerations. A heat exchanger will be installed in an experimental house in order to observe its contaminant removal and energy conserving attributes. Other contaminant removal schemes will be investigated for energy efficiency and air pollution control.

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Hospitals Program

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INTRODUCTION

With funding from the Department of Energy's (DOE) Division of Buildings and Community Systems, work on the Hospitals Program began in August 1977. The Hospital Program is a component of Lawrence Berkeley Laboratory's (LBL) Energy Efficient Buildings (EEB) Program, and is closely coordinated with the Ventilation Program.

In the United States, hospitals account for approximately 12% of all energy used in institutional and commercial buildings (or 1.1×10^{15} Btu).[1] This is equivalent to an annual nationwide outlay of 2.7 billion dollars at 1978 prices. In large part, this substantial expenditure is a result of the usual practice of U.S. hospitals to follow standards of design and operation (based on state and federal requirements) that provide the best possible environment for patients and staff, without giving full consideration to energy conservation opportunities.

We have singled out hospitals for special study because of their relatively large energy use. Hospitals are considerably more energy-intensive than most other buildings, especially for space and water heating, and for cooling (see Fig. 1) Heating ventilation and air conditioning (HVAC) systems use more than 50% of the energy consumed in hospitals, with lighting and water the next two largest areas of use (see Fig. 2). LBL's Hospitals Program staff is looking closely at energy conservation opportunities in the HVAC systems, as well as in other hospital areas (e.g., water use, lighting requirements).

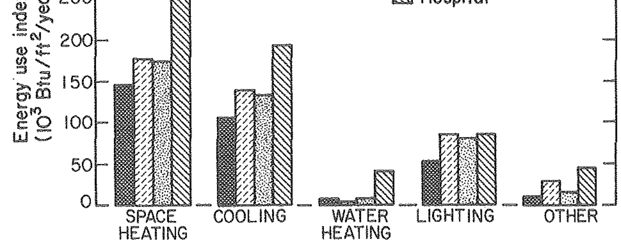

Fig. 1. Energy use indicies for educational, retail, office, and hospital buildings, 1970.[1] Energy use in primary units. (XBL 7810-11637)

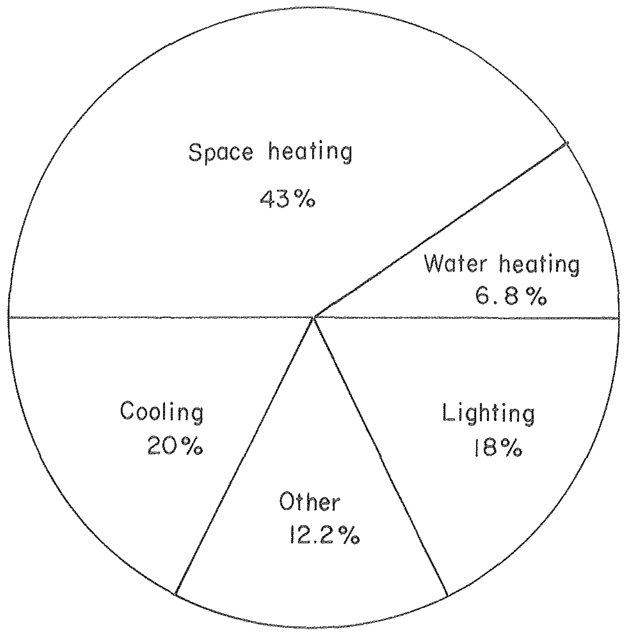

Fig. 2. Hospital energy use in 1975.[1] Energy use calculated in resource or primary units. To account for conversion losses, the primary energy for electricity has been calculated in terms of 10,383 Btu/KWhr (the average heat rate estimated by the Edison Electric Institue for 1975). In addition, 9% electrical transmission-distribution losses have been assumed. (XBL 792-439)

A large percentage of the hospital community today believes that hospital patients may be more susceptible than the healthy population to airborne infections, to the deleterious effects of high concentrations of odors and chemical contaminants, and to changes in temperature and relative humidity. For this reason, the hospital design standards currently in existence, as exemplified by the Hill-Burton standards of the U.S. Department of Health, Education and Welfare (HEW), are extremely conservative. The ultimate objective of the LBL Hospitals Program is to develop energy conservation strategies which do not compromise the health, safety, and comfort of patients and staff.

With passage of the National Energy Act (NEA) in late 1978, the cost-effective energy conservation measures being identified by the Hospitals Program take on even more importance. The NEA will make funds available (on a cost-sharing basis) to many hospitals for energy audits and for energy-conserving retrofits. LBL's Hospitals Program will play a major role in disseminating information to hospitals about these cost-effective energy-conserving retrofits.

OBJECTIVES

The goals of the Hospitals Program are:

1) Assessment of the effects of energy conservation measures on indoor air quality (including air chemical content, microbial burden, odors and comfort factors) in hospitals, before and after energy-conserving retrofits, and in new "energy-efficient design" hospitals.

2) Development of cost-effective energy conservation measures.

3) Rapid transfer of advanced energy conservation technology in practical format to users.

In order to achieve these goals, LBL undertook in 1978 a number of different tasks:

1) A review of current hospital, ventilation and thermal standards with recommendations for hospital energy conservation opportunities compatible with the health, safety, and comfort of the staff and patients (subcontract to the University of Minnesota);

2) A study of energy-efficient water use in hospitals (subcontract to Hittman Associates, Inc.);

3) A baseline study on indoor air quality at the Naval Regional Medical Center (NRMC) in Long Beach, California, performed by LBL using the EEB Mobile Laboratory (see "Ventilation Program") and the University of California Naval Biosciences Laboratory, as well as an energy study of the NRMC (subcontract to the Consultants Computation Bureau); and

4) The groundwork for establishment of LBL as a coordinating and information dissemination center for energy conservation practices in hospitals (performed by the Hospitals Program staff).

Under the sponsorship of DOE and HEW, it is expected that a uniform set of energy efficient hospital ventilation, thermal, and water use standards will eventually be adopted by federal, state and local governments and the hospital community as a whole.

VENTILATION STANDARDS: ASSESSMENT AND DEVELOPMENT

The University of Minnesota's School of Public Health, under a subcontract managed by LBL's Hospitals Program staff, examined current hospital ventilation standards to determine if they could be relaxed on the basis of criteria that do not compromise the health, safety, and comfort of patients and staff. As part of this project, the University of Minnesota School of Public Health convened, in February 1978, an International Working Conference on Hospital Ventilation Standards and Energy Conservation. The conference brought together an International Advisory Panel of six American and four European experts in the field, as well as fifteen observers. In brief, the major findings of the conference[2] were:

1) Hospitals in general are over-ventilated, and some reduction in ventilation rates seems possible. However, care must be exercised so that specific micro-environments, such as the operating and delivery rooms, are adequately ventilated.

2) High ventilation rates have traditionally been assumed necessary in the hospital for control of airborne infections. However, current studies indicate that airborne infections are only a very minor part of the overall hospital infection problem and would not be measurably affected by some reduction of ventilation air. The conference also reported that poor hygienic practices permitting interperson transfer of pathogenic microbes are the principal determinants of hospital-acquired infections.

3) Humidity does not need to be controlled on the basis of human comfort. Other factors, such as the control of static electricity, should define humidity endpoints.

4) The control of chemical contaminants is probably the limiting constraint on ventilation requirements. At the present time, no information exists to adequately characterize the airborne chemical load in the hospital setting.

5) Rather than setting basic ventilation rates to dilute odors below their olfactory thresholds, odors should be controlled at their point source. The conference also stressed that Yaglou's seminal work on the subject (see "Ventilation Program") needs updating in the context of today's technology and changed cultural environment.

The University of Minnesota issued a report, Hospital Ventilation Standards and Energy Conservation: A Summary of the Literature with Conclusions and Recommendations, FY'78 Final Report, which was published in September 1978.[3] In this report there is a discussion of hospital ventilation and thermal standards, the role of air in hospital-acquired infections, chemical contamination of hospital air, and the effect of thermal factors and odors on the patient care environment. Much of the information comes from an extensive literature survey[4] undertaken by the University of Minnesota in 1977. The final chapter of this report includes conclusions and recommendations developed from the literature review, as well as from the international conference.

In December 1978, the University of Minnesota distributed proposed modifications of ventilation and thermal standards in hospitals to various government agencies, organizations, and individuals concerned with both energy conservation and the quality of the patient care environment. Table 1 summarizes their recommendation in

Table 1. Differences between Hill-Burton 79-14500 standard and the University of Minnesota discussion standard for hospital ventilation and thermal conditions for selected areas.

Area	Outdoor Air Changes		Recirculation By Room Unit		Temperature	
	Hill-Burton Standard	Proposed Standard	Hill-Burton Standard	Proposed Standard	Hill-Burton Standard	Proposed Standard
PATIENT ROOM	2	1			75	68-78
PATIENT CORRIDOR	2	1			75	68-78
EXAMINATION ROOM	2	1			75	68-78
MEDICATION ROOM	2	1			72	68-78
PHARMACY	2	1			72	68-78
TREATMENT ROOM	2	1			75	68-78
X-RAY, FLUORO-SCOPY ROOM	2	1	No	Optional	75	68-78
X-RAY, TREATMENT ROOM	2	1			75	68-78
PHYSICAL THERAPY & HYDROTHERAPY	2	1			75	68-78
SOLID UTILITY	2	1			72	68-78
CLEAN UTILITY	2	1			72	68-78
AUTOPSY	2	1			72	68-78
WORKROOM	2	1	No	Optional	72	68-78
LABORATORY, GENERAL	2	1			72	68-78
LABORATORY, MEDIA TRANSFER	2	1			72	68-78
FOOD PREPARATION CENTERS	2	1			72	68-78
LAUNDRY, GENERAL	2	1	No	Optional	72	68-78
CENTRAL SUPPLY SOILED ROOM					72	68-78
CLEAN WORKROOM					72	68-78
TRAUMA ROOM					75	70-76
NURSERY SUITE					75	72-76
RECOVERY ROOM					75	72-76
INTENSIVE CARE					72-78	72-76

comparison with the existing Hill-Burton standards. In nearly all the hospital areas considered (operating, recovery, delivery rooms, etc., are excepted), it is proposed that minimum ventilation be reduced from two to one air change(s) per hour. In all areas except in the operating, trauma, delivery and recovery rooms, nursery suite and intensive care unit, it is recommended that design temperature shall be 68°F for heating and 78°F for cooling. By comparison, the Hill-Burton 79-114500 Standard specifies 72°F or 75°F for each space. Except for the six areas noted above, proposed design criteria suggest a minimum level of relative humidity of 30% during the heating season. For cooling, it is suggested that humidity levels be selected within the comfort envelope defined by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55-74, entitled Thermal Environmental Conditions for Human Occupancy,[5] for minimum total HVAC system energy use. If implemented, this standard would replace a maximum humidity level of 60% in most of these areas under Hill-Burton 79-14500.

Planned Activities for 1979

The University of Minnesota intends to compile a set of recommended changes in hospital ventilation and thermal standards after written comments on its draft standards are received and analyzed. In April 1979 a meeting will be held under DOE and HEW auspices to discuss the acceptability of the composite standards. Technically-oriented members of the hospital professional community (for example, certain members of ASHRAE, American Hospital Association (AHA) and HEW) will be invited to this meeting. Following publication of final recommended ventilation and thermal standards by the University of Minnesota in the Summer of 1979, LBL will seek adoption of the revised standards at all levels though coordination with representatives of HEW (Health Resources Administration, Hill-Burton staff, and Communicative Diseases Center) DOE, ASHRAE, Veterans Administration, Department of Defense, Bureau of Indian Affairs, the hospital operating group of the Public Health Service, AHA, the Joint Committee for the Accreditation of Hospitals and other appropriate groups. It is estimated that if the modifications in ventilation standards are implemented in 25% of the existing hospitals, then 15×10^{12} Btu, or 1.5% of the total hospital yearly energy budget can be saved with minimal cost.

The University of Minnesota, under subcontract to LBL, will conduct a study of chemicals in hospitals. This study will involve a survey of several Minnesota hospitals in order to catalog toxicity, carcinogenicity, flammability, and other characteristics of chemicals found in hospital environments. The University of Minnesota will recommend control measures for the chemicals catalogued in an effort to minimize the impact of these chemicals on indoor air quality.

ENERGY EFFICIENT WATER USE IN HOSPITALS

In order to identify water-related energy conservation measures which can be implemented by hospitals without adversely affecting the patient care environment, LBL awarded a contract in October 1978 to Hittman Associates,

Table 2. Benefit cost matrix for identified hospital water heating conservation opportunities.

Conservation Measure	Annual Energy Savings (Therms/Year)	Cost Savings ($/Year)	Cost Savings (%)	Energy Savings (%)	Cost ($)	Payback (Months)
Repair Leaks in Piping	1,095	281	2.1	2.0	Minimal	Immediate
Use of Cold and 140°F Water in Laundry	41,750	10,040	76.6	74.9	4,200	5.0
Use of Cold Water in Floor & Bathroom Cleaning	511	96	0.7	0.9	Minimal	Immediate
Use of Cold Water in Dishwater Pre-Rinse	9,772	1,837	14.0	17.5	Minimal	Immediate
Lowering Dishwasher Temperature to 100°F from 160°F	1,844	442	3.4	3.3	3,000	81.4
Reduce Water Flow Rate in X-Ray Film Processing	808	405	3.2	1.4	Minimal	Immediate
TOTAL:	55,780	13,101	100	100	7,200	6.6

Inc. to study energy efficient water use in hospitals. The scope of work for this study is:

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.

Drawing upon the preliminary findings obtained by the Hittman study[6], Table 2 illustrates potential energy and cost savings that could be achieved by more efficient use of water in a "typical" hospital with a 200-bed capacity. Conservation measures numbers 2 and 5 in Table 2 require replacement of existing equipment with equipment designed for operation at low temperatures. Costs shown are estimated differential costs above the costs of conventional equipment, assuming equipment would have to be replaced in time anyway.

The Hittman study should result in the development of a comprehensive guide on methods for reducing the quantity of energy expended on the heating of water in hospitals.

Planned Activities for 1979

In 1979, the Hittman study on "Energy Efficient Water Use in Hospitals" will be completed, and results of the study will be available for implementation. Following completion of the study, the LBL Hospitals Program staff intends to select an appropriate site (several negotiations are currently underway), and conduct programs to test the results of the study. First, hot water energy use in existing operation will be measured, and then the appropriate recommendations from the Hittman study will be implemented. To provide a real-world validation of the savings predicted by the Hittman study, the hot water energy use will again be measured, and the level of sanitation evaluated.

FIELD STUDIES DEMONSTRATING ENERGY CONSERVATION OPPORTUNITIES IN HOSPITALS

The previously described studies (University of Minnesota and Hittman) have identified energy conservation opportunities (ECOs) in the ventilation, thermal and water use systems in hospitals. The LBL Hospitals Program staff is conducting field studies demonstrating the application of these ECOs and assessing their impact on the hospital care environment.

Initial work is focusing on indoor air quality measurements before and after ventilation system retrofits. LBL, using the EEB Mobile Laboratory, performed a baseline study on indoor air quality at the Naval Regional Medical Center (NRMC) in Long Beach, California, in September and October, 1978. Air quality parameters, including chemical and microbial contaminants, were monitored in several different patient care areas, including an examination room, a cast removal area, and a four-patient ward room. Some of the microbial sampling was done in a cast removal room to consider "worst case" conditions. Detailed analysis of the baseline air quality data is in progress. This baseline data, obtained while the HVAC system was operated under conditions consistent with present ventilation and thermal standards, will be compared with data gathered during 1979 following implementation of a series of energy conservation measures.

To understand and model the NRMC energy consumption, and to develop the most favorable set of ECOs, LBL subcontracted with Consultants Computation Bureau (CCB) to perform an energy analysis of the NRMC.[7] The study consisted of the following elements:

1) Construction of a computer simulation of the hospital for use an an analytical tool in the course of the present study, and for possible future energy analyses of the hospital.

2) Analysis of the present modes and levels of energy conservation.

3) Identification, analysis and ranking of ECOs.

The computer model used in this study was the public domain DOE-1 model, which CCB ran on LBL computing facilities. The final computer simulation of the hospital matched actual energy consumption quite closely for the year chosen, 1975.

Table 3 illustrates the predicted savings that can be achieved through the utilization of a combination of economically-feasible ECOs, including: (1) temperature-controlled economizer on an assembly hall air conditioning system; (2) expanded thermostat throttling ranges; (3) night shutdown of selected fan systems; (4) elimination of air tempering in some systems, and control of hot and cold duct temperatures by zone of greatest demand in other systems; (5) and division of one large air handling system into two smaller systems, permitting night shutdown of the larger of the two systems. It has been calculated that the cost to implement these changes is approximately $170,000, the life cycle cost savings (25 year life cycle) are $4,000,000, the reduction in resource energy consumption for the chosen year is 31.8%, and the annual savings amount to $164,000 for a payback period of one year.

The engineering design for a series of modifications to a portion of the heating, ventilating and air conditioning system at NRMC Long Beach has bee completed. These changes will implement some of the more favorable ECOs as determined by the CCB study, and will permit implementation of the reduced ventilation levels proposed by the University of Minnesota study.

Table 3. Predicted energy savings (in 10^9 BTU/year) through the utilization of energy conservation opportunities (ECOs).

		Boundary*		Resource+	BTU/Gross Sq. Ft.-Year	
	Fossil	Electric	Total	Total	Boundary*	Resource+
1975 Base	73.875	46.194	120.070	212.472	252,248	446,370
Combined ECO's	41.685	34.663	76.348	145.684	160,395	306,059
% Reduction	43.6	25	36.4	31.4	36.4	31.4

*Boundary energy use is the actual consumption of fuel and electricity within the confines of of the facility. The conversion 1 KWH = 3413 BTU is used.

+Resource energy uses imposes a factor of 3 on electrical energy use within the boundary to to account for generation, transformation, and distribution losses.

Planned Activities For 1979

To determine if proposed energy conservation alterations are detrimental to air quality, mechanical alterations to selected areas of the Long Beach NRMC will be completed in late spring of 1979. These mechanical alterations are based in part on the recommended ventilation and thermal standards proposed by the University of Minnesota. These measures will be implemented on a double duct air handling system serving an outpatient area. These include changing the existing temperature-controlled economizer to enthalpy control; modifications to the duct temperature control systems to provide just enough heat to satisfy the coldest zone, and just enough cooling to satisfy the hottest zone; and closed-loop control of outside air, supply air, and return air quantities at selected values. Finally, humidity will be controlled only to maintain a minimum of 30% relative humidity in the space. To determine the effects of these alterations, BTU energy measuring systems will be installed on heating and cooling coils of the selected air handler. Each of these systems consists of a vortex-shedding flow meter, supply and return temperature sensors, and analog devices to integrate the product of flow and temperature difference to determine BTU energy consumption of the coil.

During 1979, the EEB Mobile Laboratory will return to the Long Beach NRMC to determine what effect the energy-saving alterations described above and the implementations of the University of Minnesota recommendations will have had on indoor air quality. The CCB-predicted savings will be validated and the University of Minnesota recommendations will be released on the basis of these results.

Studies similar to those being conducted at the Naval Regional Medical Center will be performed at a hospital in a more severe climate. Discussions are in progress with the Veterans Administration (VA); the VA Hospital in Omaha, Nebraska is the most probable site for these studies. These studies, to be initiated in 1979 and completed by late 1980, will include an energy audit, modifications to the ventilation system, indoor air quality studies to determine the impact of the ventilation modifications, and demonstration projects for waste water heat recovery and gray water re-use.

DISSEMINATING INFORMATION AND COORDINATING RESEARCH

In addition to coordinating and performing research to gain information on hospital energy conservation, the Hospitals Program staff is assuming a central role in disseminating such information. Results of the University of Minnesota study, recommending relaxation of ventilation and thermal standards in most areas of a hospital, are crucially important for reducing energy use in hospitals. Consequently, the Hospital Program staff presented these findings at a recent meeting of the American Hospital Association and participated in informal meetings with several federal and state agencies to facilitate widespread acceptance of the revised standards by national and local code-making and code-enforcing agencies. The Hospitals Program staff participated in a series of meetings and presentations during 1978, both to effect inter-agency coordination of present and future demonstration projects, and to present results of current research to interested groups.

Planned Activities For 1979

The Hospitals Program staff plans a major effort to become a clearinghouse for energy conservation information relating to hospitals, including assessment of ventilation and thermal standards on energy consumption, and methods for reducing hot water energy use in hospitals. Consequently, during 1979, the Hospitals Program will disseminate the results of its research to federal and state agencies, professional societies, hospital associations, and individual hospitals through a series of meetings, presentations and symposia.

In 1979, an annotated bibliography of energy audit source materials will be prepared at Lawrence Berkeley Laboratory and published. This bibliography should help individual institutions and state energy agencies to implement the energy audit provisions of the 1978 U. S. National Energy Act.

Finally, also in 1979, the University of Minnesota will conduct a survey of hospital energy conservation activities of state and federal agencies with the aim of disseminating this information to interested parties.

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