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# Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

## ENERGY & ENVIRONMENT DIVISION



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May 1981





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## DISCLAIMER

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ABSTRACT

The Lawrence Berkeley Laboratory assessed the indoor air quality at Oakland Gardens Elementary School in New York City under three different ventilation rates. A mobile laboratory was used to monitor air quality in two classrooms, a hallway, and outdoors. The parameters measured were air exchange rates, particulates, odor perception, carbon dioxide, carbon monoxide, sulfur dioxide, ozone, nitrogen oxides, radon, formaldehyde and total aldehydes. When the ventilation rate was reduced, carbon dioxide concentrations increased significantly, but did not exceed current occupational standards. At the low ventilation rate, odor acceptability decreased and in one of the classrooms the odors were judged unacceptable according to current ASHRAE standards. Calculations indicate that moderate energy savings can be achieved by reducing the ventilation rate in the classrooms.

keywords: air pollution, carbon dioxide, carbon monoxide, energy conservation, indoor air quality, nitrogen oxides, odors, particulate mass, schools, sulfur dioxide, ventilation.

INTRODUCTION

Rising energy costs have motivated school administrators to review their energy consumption patterns. The possibility of energy savings is significant: schools alone account for 3% of the primary energy consumed in the United States (approximately $1.87 \times 10^9$ gigajoules/yr or $1.77 \times 10^{15}$ Btu/yr). More than half of the energy used by institutional buildings, such as schools, is for heating, cooling, and ventilation to maintain the comfort of the building occupants (see Figure 1). Heating or cooling outside air as it enters the building requires a significant amount of energy. Reducing the volume of outside air that has to be heated will reduce energy consumption and effect considerable dollar savings.

Lowering the ventilation rate, however, may adversely affect indoor air quality. Although pollution is normally associated with the outdoor environment, a number of pollutants have indoor sources or are found in higher concentrations indoors. For example, carbon dioxide is a by-product of human respiration; formaldehyde and other organic compounds come from building materials and furniture; odors come from the occupants themselves and their activities (cleaning, painting, etc.); nitrogen oxides, carbon monoxide, carbon dioxide, and many organic compounds are products of combustion. In conventional buildings, natural infiltration and/or a mechanical ventilation system allows air to enter the building to dilute or remove indoor-generated pollutants. When the ventilation rate is reduced, these indoor-generated contaminants can build up to levels that could possibly impair the health, safety, or comfort of the occupants.

There is no national standard for ventilation rates in buildings. The most widely accepted standards are those of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). ASHRAE Standard 62-73, entitled _Standards for Natural and Mechanical Ventilation_,[1] gives minimum and recommended ventilation rates for several types of building spaces. The first part of section 6.5 of this standard pertains to schools and is presented in Table 1. The recommended outside air quantity requirements appear to be based largely on odor research performed over forty years ago by C.P. Yaglou et al.[2] at Harvard University's School of Public Health. The ventilation requirements given are for 100% outdoor air; where recirculation of air is permitted, a reduction to 15% of the specified required ventilation rate is allowed if adequate temperature control, particulate filters, and high efficiency odor and gas removal equipment are employed so that the air entering the building space has been purified to meet specified air quality requirements. ASHRAE additionally specifies that "in no case shall the outdoor air quantity by reduced to less than 5 cfm per person." In response to demands for energy conservation in buildings, ASHRAE published a new standard in 1975. This standard, ASHRAE 90-75R, _Energy Conservation in New Building Design_,[3] has stipulated that the minimum ventilation rate for each type of occupancy given in ASHRAE 62-73 must be used in designing new buildings. At present, the ASHRAE standard for minimum quantity of ventilation air for classrooms in _new_ schools is 16.9 $m^3/h$ (10 cfm) per occupant. In systems with recirculated air. a reduction to 8.5 $m^3/h$ (5 cfm) per occupant is permitted if the air is purified to meet certain prescribed air quality requirements.

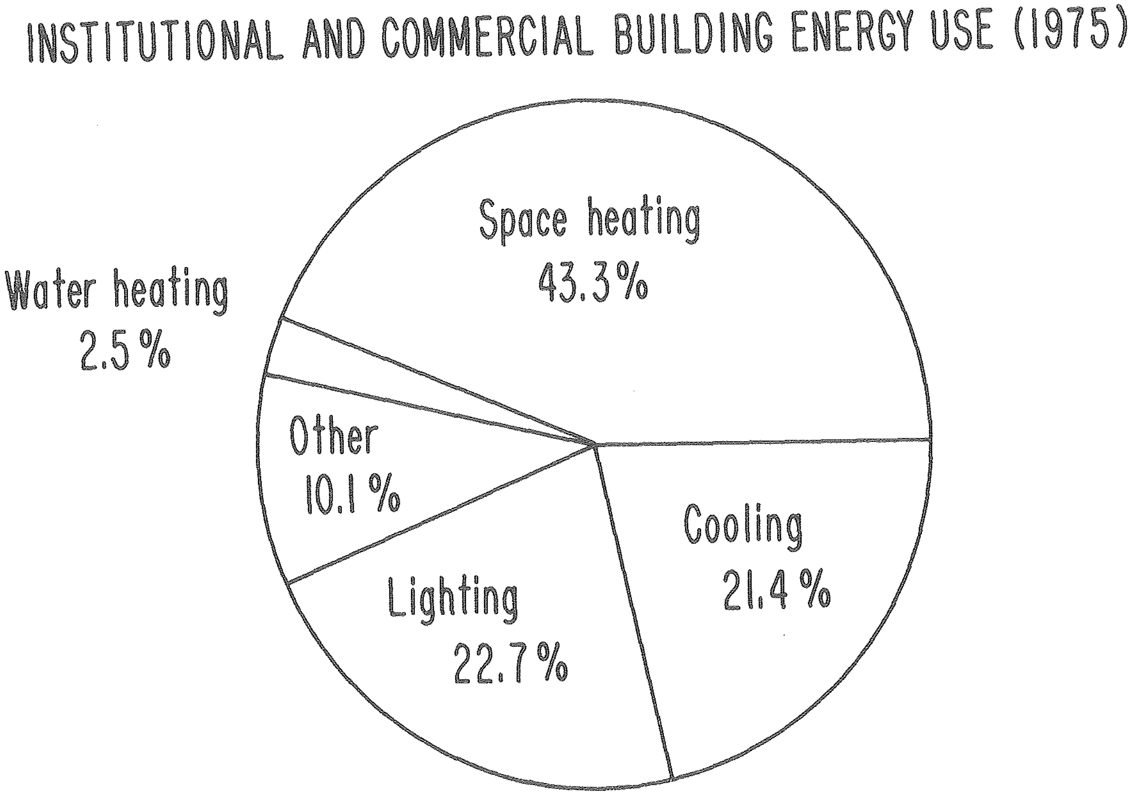


Figure 1. Primary energy use for all non-residential buildings divided into four main functional uses (from Oak Ridge National Laboratory, Commercial Energy Use: A Disaggregation by Fuel, Building Type and End Use, ORNL/CON-14)

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Table 1. Ventilation standards for schools (ASHRAE 62-73).

| | Estimated persons/ 1000 sq ft floor area. Use only when design occupancy is not known | Required ventilation air, cubic feet per minute per human occupant, (when the number is bracketed, refer to the notes). | | Comments |
|---|---|---|---|---|
| | | Minimum | Recommended | |
| Schools | | | | |
| Classrooms | 50 | 10 | 10-15 | |
| Multiple Use Rooms | 70 | 10 | 10-15 | |
| Laboratories | 30 | 10 | 10-15 | * |
| Craft Shops, Vocational Training Shops | 30 | 10 | 10-15 | * |
| Music, Rehearsal Rooms | 70 | 10 | 15-20 | |
| Auditoriums | 150 | 5 | 5-7½ | |
| Gymnasiums | 70 | 20 | 25-30 | |
| Libraries | 20 | 7 | 10-12 | |
| Common Rooms, Lounges | 70 | 10 | 10-15 | |
| Offices | 10 | 7 | 10-15 | |
| Lavatories | 100 | 15 | 20-25 | |
| Locker Rooms | 20 | (30) | (40)-(50) | ** |
| Lunchrooms, Dining Halls | 100 | 10 | 15-20 | |
| Corridors | 50 | 15 | 20-25 | |
| Utility Rooms | 3 | 5 | 7-10 | |
| Dormitory Bedrooms | 20 | 7 | 10-15 | |

*Special contaminant control systems may be required
**cfm/locker

(For existing schools, the recommended ventilation rate for classrooms is 16.9-25.4 $m^3/h$ or 10-15 cfm per occupant).

Implementation of the lower ventilation rates in Standard 90-75R raised questions concerning the indoor air quality in buildings, especially with regard to high levels of carbon monoxide and particulates in areas where smoking is allowed. To address the issue of energy efficient ventilation rates and a safe, healthy, and comfortable indoor environment, ASHRAE has revised Standard 62-73. The new standard, ASHRAE 62-81, Ventilation for Acceptable Indoor Air Quality,[4] has recently been approved and will be issued in 1981. Different requirements are specified for smoking and non-smoking areas. The smoking areas have requirements which are higher than the non-smoking areas. For classrooms in schools, the minimum outdoor air requirements are 8.5 $m^3/h$ (5 cfm) for non-smoking areas and 42.2 $m^3/h$ (25 cfm) for smoking areas.

Interest in energy efficient ventilation rates has focused attention on air quality of indoor environments. To determine the effects of more energy-efficient ventilation rates, the Building Ventilation and Indoor Air Quality Program at Lawrence Berkeley Laboratory (LBL) has designed the "Energy Efficient Buildings (EEB) Mobile Laboratory" as a means of conducting field studies in various types of buildings. We have used the mobile laboratory to monitor indoor air quality in schools under different ventilation rates. Initial studies were conducted at a California high school[5] and an Ohio elementary school.[6] The Oakland Gardens Elementary School, P.S. 203, in New York City was the third school where indoor air quality was monitored by the EEB Mobile Lab. In this study, we focused on measuring odors, particulates, and gaseous pollutants at three different ventilation rates. The odors measurements were conducted by The Research Corporation of New England (TRC) under subcontract to LBL.

## EXPERIMENTAL FACILITIES AND METHODS

The field study of indoor air quality at the Oakland Gardens Elementary School took place from November 10, 1979, to January 18, 1980. The school building, the experimental procedures, the mobile laboratory used for monitoring indoor air quality, and the sampling techniques to measure odors are described below.

### The School Building and Mechanical Ventilation System

The Oakland Gardens Elementary School (P.S. 203), located at 5411 Springfield Blvd, Bayside, Queens NY, is a three story building constructed in 1961. In the basement of the school are the boiler room, kitchen, and student lunchroom. The three upper floors house 36 classrooms, a library, and administrative offices. An attachment on the north side of the building contains the gymnasium (upper floor) and an an auditorium (lower floor). The total area of the entire school is 7339 $m^2$ (79,000 $ft^2$).

During normal school hours (8:30 A.M. to 3:30 P.M.), there are generally 35-40 students in each classroom. The volume of each room is 219 $m^3$ or 7716 $ft^3$ (dimensions of the classrooms are 8.7 X 8.7 X 2.9 m or 28.5 X 28.5 X 9.5 ft). Each room is heated by steam fin-tube radiation heaters, which are thermostatically controlled. Two oil-fired boilers, which are operated manually by the school fireman, provide hot water and steam to the individual room heaters.

Most classrooms have three exhaust vents: two in the student coat closets and one by the door. Exhaust fans. located on the roof, draw air from the exhaust vents inside the rooms directly to the roof. There is no recirculation of air inside the building. Since there are no air intake registers, ventilation air arises solely from infiltration of air through cracks around the windows and doors.

## Experimental Procedures and Ventilation Rates

We had originally planned to monitor three classrooms on the third floor of the school; however, because one of the classrooms was not occupied, we selected the hallway as the third site. The three indoor sites were Room 323, Room 325, and the hallway between the two classrooms. Both classrooms were occupied by fifth-grade students.

The two exhaust vents in the coat closets were sealed and the flow of air through the third vent by the door was determined using an instrument that averages the velocity measurements from multiple sensors spaced in an equal-area traverse. We found that the air flow rate through the exhaust vent was very low compared to total air flow in the room during unoccupied periods as measured by the tracer gas decay technique.* Therefore, all subsequent infiltration rates were measured by tracer gas decay using either nitrous oxide ($N_2O$) or sulfur hexafluoride ($SF_6$) during times when the rooms were unoccupied and the windows and doors were closed. All calculations of the ventilation rate are averages of 5-6 measurements taken on different days and are based on an occupancy of 40 students in each classroom.

We began by monitoring the air quality under the existing school heating and ventilation conditions. It must be noted that under these conditions all exhaust vents were open but the exhaust fans off, and the room heaters were under thermostat control. However, because the infiltration rate was very low (1.2 $m^3$/h or 0.7 cfm per occupant) with the exhaust fans off, the carbon dioxide levels rose to 9000 mg/$m^3$ (5000 ppm) in less than three hours. When the $CO_2$ levels exceeded 9000 mg/$m^3$ (5000 ppm), we turned on the exhaust fans. The higher infiltration rate in the classrooms when the exhaust fans were on and all three exhaust vents open (45.5 $m^3$/h or 27.0 cfm per occupant) rapidly lowered the $CO_2$ concentrations. We then decided to monitor under three ventilation

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* Using a smoke pencil, we determined that air was leaving the classroom from cracks in the wall and around the light and clock fixtures, in addition to the air leaving through the exhaust vent.

rates between these two extremes and the exhaust fans were always on at all times during our testing in order to keep the $CO_2$ levels below the 9000 mg/m$^3$ (5000 ppm) standard of the Occupational Safety and Health Agency (OSHA)[7]. Even though this standard is set for a time-weighted average of 8 hours, we did not want to exceed this level during our testing.

The first rate, which we shall call the "high" ventilation rate, was approximately 14.8 m$^3$/h (8.8 cfm) per occupant. This ventilation rate was achieved by sealing the two exhaust vents in the student coat closets and leaving the third exhaust grille by the door completely unhindered. An "intermediate" ventilation rate of approximately 8.2 m$^3$/h (4.9 cfm) per occupant was then obtained by partially covering approximately half of the third exhaust grille. A third, "low" ventilation rate (4.4 m$^3$/h or 2.9 cfm per occupant) was achieved by almost completely covering the third vent. (Figure 2 shows the third exhaust grille by the door when it is open and partially taped in the intermediate mode.) Tracer gas measurements were made in both classrooms to assure uniform ventilation rates in each room during monitoring.

We monitored the indoor air quality for approximately seven weeks, between two and three weeks at each ventilation rate. During the monitoring period, we asked the students to keep the doors to Rooms 323 and 325 closed: this request was generally honored. Except for odors, all air quality parameters were measured by the EEB Mobile Laboratory.

## The EEB Mobile Laboratory: Description and Indoor Air Quality Parameters Monitored

The EEB Mobile Laboratory, shown in Figure 3 beside the school, is a semi-trailer that has been modified for use as a laboratory.[8] It contains sampling, calibration, and monitoring systems for field studies of indoor air quality in buildings. Table 2 shows the instrumentation in the EEB Mobile Lab and the parameters it is designed to monitor.

For those parameters that were measured on a continuous basis (temperature, humidity, carbon dioxide, carbon monoxide, sulfur dioxide, ozone, and nitrogen oxides), connection between the indoor sites and the mobile lab was made by electrical cable and teflon sampling lines. At each sampling site were a sampling line inlet and sensors to measure temperature and humidity. (Figure 4 shows the sampling lines and sensors suspended from the ceiling in Room 325.) For analysis of the common gaseous inorganic pollutants, air from the three indoor sites and one outdoor site was drawn into the trailer and directed to a glass sampling manifold from which the various instruments withdrew air for analysis. The four lines were sampled in sequence under the control of a microprocessor, which automatically energized specific solenoids and then recorded the data on a floppy disk. The microprocessor also directed a daily calibration of the analyzers. In this study, the sites were sampled sequentially for ten-minute intervals; thus, each site was monitored for a ten-minute period every forty minutes.

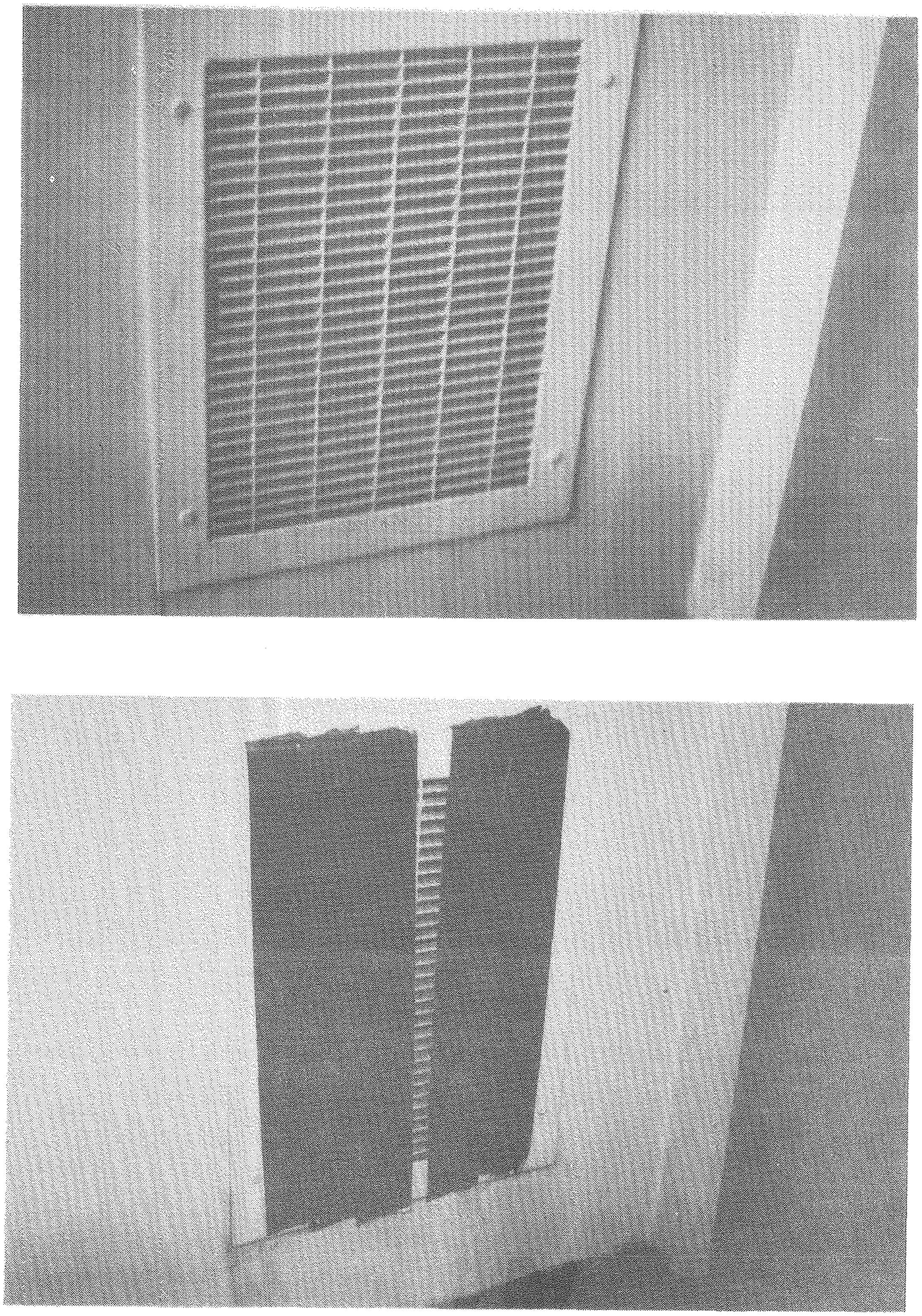

Figure 2. Upper Photo: Exhaust grille by the door in one of the classrooms monitored.
Lower Photo: Exhaust grille by the door partially sealed with duct tape to lower the ventilation rate to the intermediate mode. (CBB808-9008)

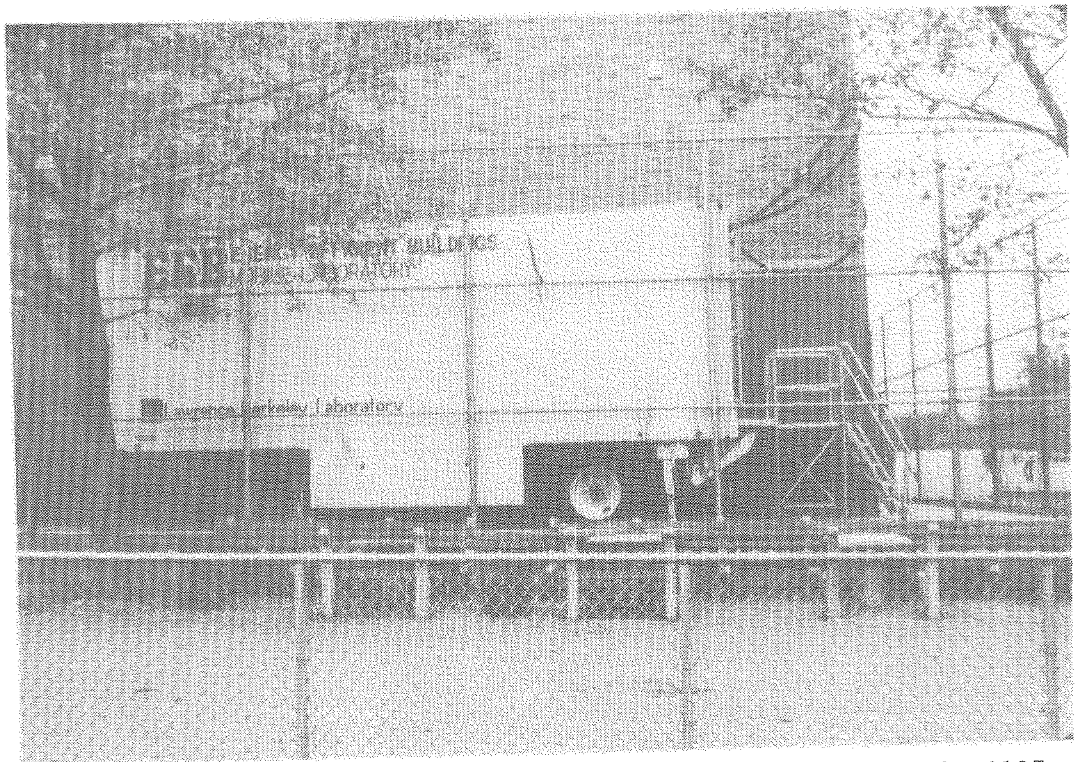

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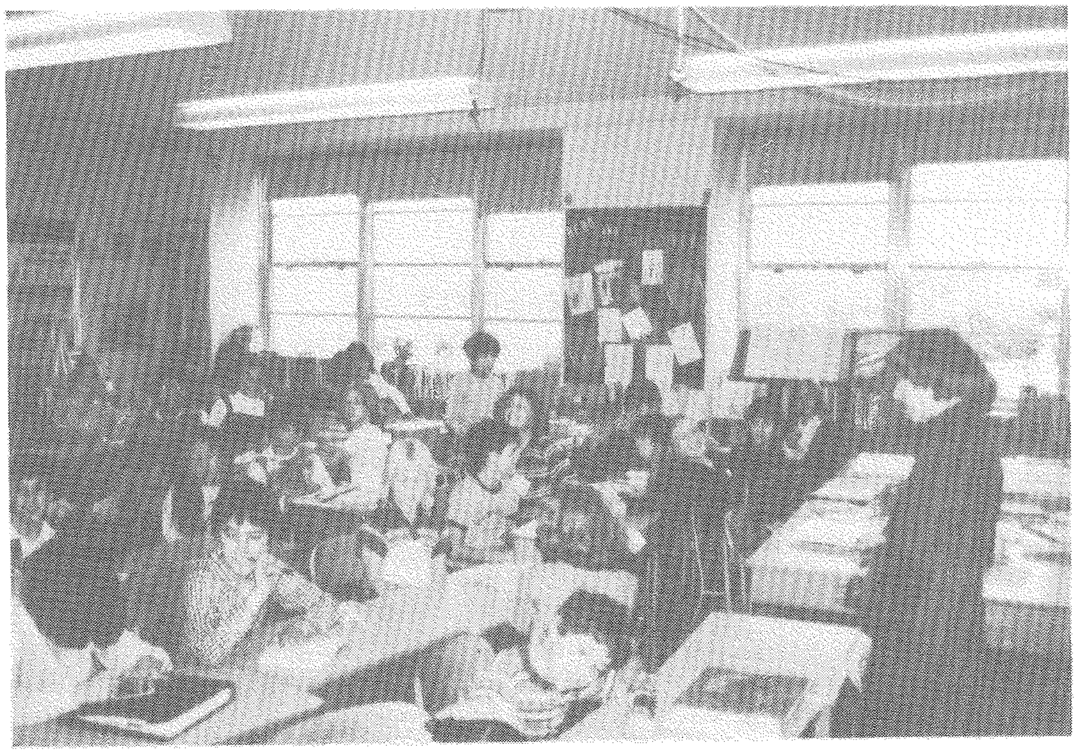
Figure 3. The EEB Mobile Laboratory stationed at Oakland Gardens Elementary School (P.S. 203), New York City.

Table 2. Instrumentation in the EEB Mobile Lab for monitoring indoor and outdoor air quality parameters.

| Purpose | Method/Instrument | Manufacturer/Model |
|---|---|---|
| Continuous monitoring of the following parameters: | | |
| Gases: | | |
| $CO_2$ | NDIR | Horiba PIR 2000 |
| CO | NDIR | Bendix 8501-5CA |
| $SO_2$ | UV fluorescence | Thermo Electron 43 |
| NO, $NO_x$ | Chemiluminescence | Thermo Electron 14D |
| $O_3$ | UV absorption | Dasibi 1003-AH |
| Indoor temperature & moisture: | | |
| Dry-bulb temperature | Thermistor | Yellow Springs 701 |
| Relative humidity | Lithium chloride hygrometer | Yellow Springs 91 HC |
| Outdoor meteorology: | | |
| Dry-bulb temperature | Thermistor | MRI 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 |
| Infiltration | Automated controlled-flow measurement or tracer gas decay/IR absorption | LBL/Wilkes |
| Time-averaged monitoring of the following parameters: | | |
| Gases: | | |
| Radon | Electrostatic collection/ thermoluminescence | LBL |
| Formaldehyde/total aldehydes | Absorption (gas bubblers)/ colorimetry | LBL |
| Selected organic compounds | Tenax GC adsorption tubes/ GC analysis | LBL |
| Inhalable particulates (fine & coarse fractions) | Virtual impaction/ filtration | LBL |
| Data acquisition: | | |
| | Microprocessor | Intel System 80/20-4 |
| | Multiplexer A/D | Burr Brown Micromux Receiver MM6016 AA Remote MM6401 |
| | Floppy disk drive | ICOM FD3712-56/20-19 |
| | Modem | Vadic VA-317S |



CBB 807-8195

Figure 4. Sampling lines and temperature and humidity sensors in one of the classrooms monitored, Oakland Gardens Elementary School, NYC.

For those parameters measured on a time-integrated basis (see the second part of Table 2) different sampling techniques were required. The instruments used were placed inside the building and were independent of microprocessor control.

Particulate matter in Room 323, the hallway, and outdoors was measured using dichotomous air samplers (DAS). The DAS, developed at LBL,[9] uses a flow-controlled virtual impaction system to separate the aerosol into fine and coarse fractions (below 2.5 μm and between 2.5 and 15 μm, respectively). The particulate matter was collected for 24-hour periods on teflon filters. The samples were returned to LBL for analysis of mass (using beta gauge techniques) and for measurements of the concentrations of 28 elements* by X-ray fluorescence.

Formaldehyde and total aliphatic aldehydes were measured for 24-hour intervals for five weeks in Room 325 and outdoors using a flow-controlled system developed at LBL.[10] The samples were collected in gas bubblers at approximately 5°C to increase the collection efficiency, and were shipped back to LBL for analysis. Formaldehyde, which was collected in aqueous solution, was analyzed using either chromotropic acid[11] or pararosaniline.[12] Total aliphatic aldehydes were collected in solutions containing 3-methyl-2-benzothiazolinone hydrazone (MBTH) and analyzed using a standard colorimetric procedure.[11]

Radon concentrations were measured in Room 325 and the boiler room using battery-operated passive radon monitors.[13] The LBL passive monitor 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 fluoride 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 diffuses into the sensitive volume to a concentration equal to that in the surrounding air. After a sampling period of approximately one week, the chips were sent back to LBL for readout, from which the average radon concentrations were determined..

## Odor Measurements

TRC measured odor perception in its mobile odors laboratory brought to the Oakland Gardens Elementary School. These measurements were conducted for a two-week period in December 1979 under the high and low ventilation rates described above. "Odor panelists" were recruited from people in the area who were not regular occupants of the school building. Air samples from the building were collected in 100-liter Tedlar bags and brought to the odors laboratory. Four sites were tested: the two test rooms (Rooms 323 and 325), a control room (Room 322), and

*The elements analyzed are: Al, Si, S, P, Cl, Ar, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Cd, Ba, Sn, Sb, Hg, Pb.

outdoors.

At all sites, the sensory perception of odors was measured in two ways: The first method employed a forced-choice triangle olfactometer (Figure 5) for determining the number of dilutions necessary to bring an odorous air sample to a level at which 50% of the members of the odor panel could no longer detect it; this neutral level is expressed as $ED_{50}$.[14] The olfactometer is equipped with five stations; the first four present dilution ratios of 81, 27, 9, and 3, and the fifth presents the undiluted odor. There are three glass sniffing ports at each station; two supply filtered outside air and the other supplies the air from within the building in one of the five concentrations, progressing from weakest to strongest (undiluted). For each of the five concentrations, the odor panelist indicates which of the three ports he or she believes delivers odorous air. The second method for testing odor intensity, used immediately after the first, employed a device called a butanol olfactometer (Figure 6). For this test, panelists are presented with the undiluted odor and asked to compare it with progressively increasing concentrations of butanol until they perceive a match between the intensity of the butanol and the intensity of the undiluted sample.[15]

In addition to the procedures described above, both the odor panelists and the building occupants filled out questionnaires (Figure 7), giving their reaction to various aspects of the room environment, including the presence of odors, and rating each on a nine-point scale. Each aspect was also rated for acceptability.

TRC also collected air samples for laboratory analysis of the odorant composition. For this purpose, two liters of room air were passed through tubes packed with porous polymer Tenax, which adsorbs the organics and odorants present in the air. The odorants adsorbed were then identified by gas chromatographic and mass spectroscopic (GC/MS) techniques, and their character and intensity were determined by a GC/odorogram and sensory judge.

## RESULTS AND DISCUSSIONS

### Gaseous Contaminants

The data on the gaseous pollutants at the indoor sites collected during school hours (8:30 a.m. and 3:30 p.m.) were compared with outdoor levels and are displayed in histograms in the Appendix. For each pollutant the concentrations during the last four minutes of each ten-minute sampling period were averaged and these averages have been sorted into bins along the horizontal axis of the histograms. (Histograms selected for discussion are presented in the text. The Appendix contains the histograms for the hallway and each classroom of all the data on the common inorganic pollutants - carbon monoxide, carbon dioxide, sulfur dioxide, ozone, and the nitrogen oxides.) The data on aldehydes and radon is also discussed in this section. The indoor concentrations of the various pollutants can be compared with the relevant ambient air quality standards listed in Table 3.

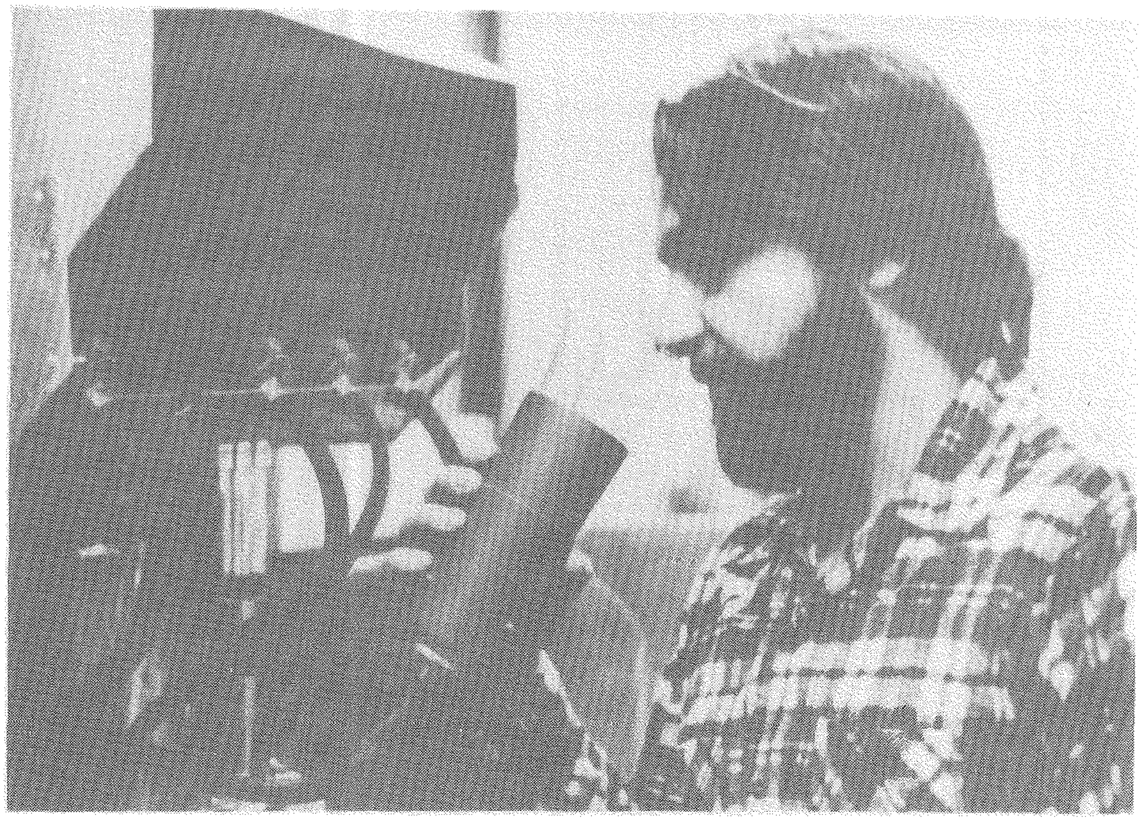


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Figure 5. Forced-choice triangle olfactometer. The subject chooses, by smell, which of the three nozzles emits odorous air.

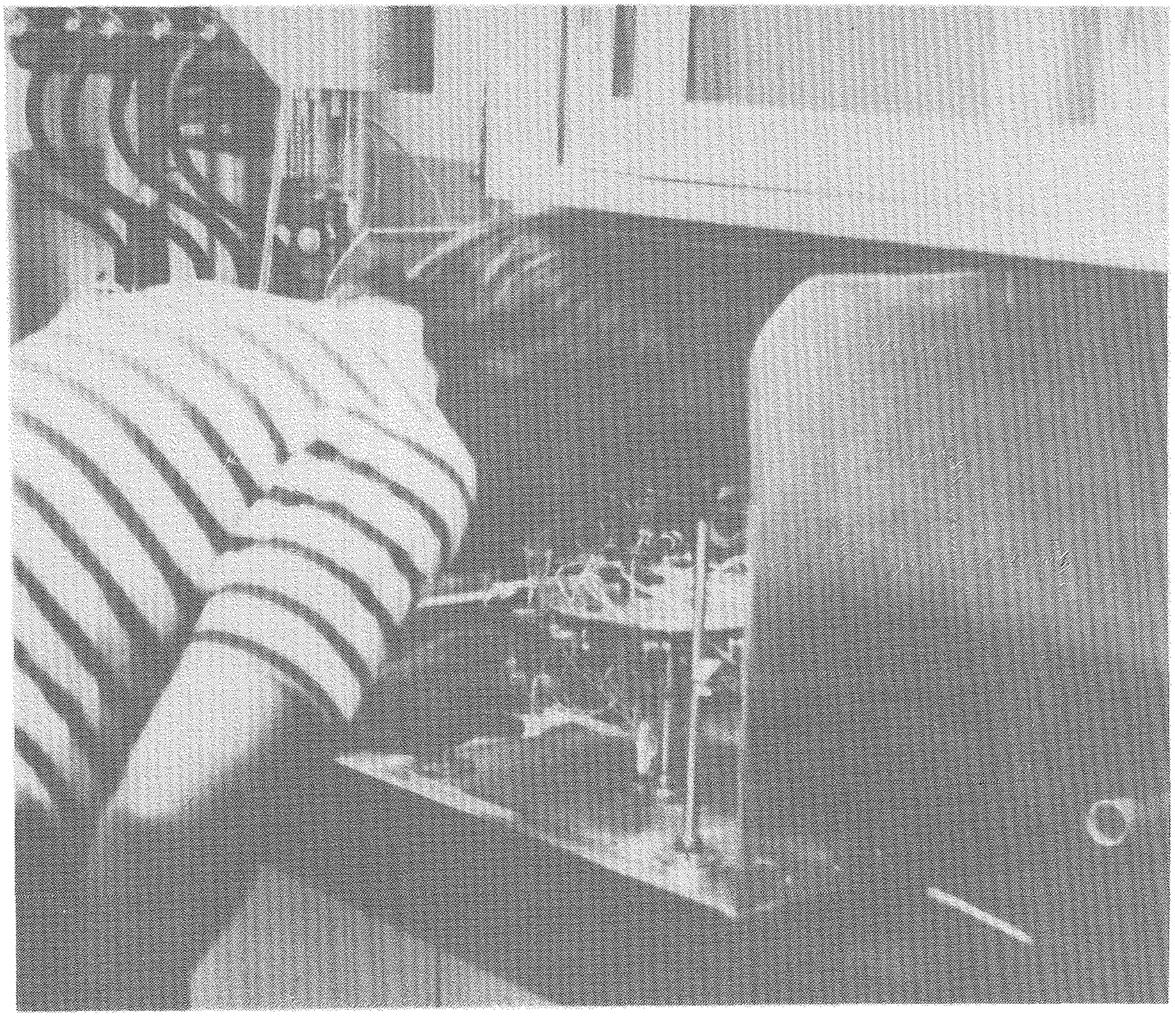

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Figure 6. Subject using the butanol binary dilution olfactometer to find a level of butanol intensity that matches the percent intensity of the "occupancy odor."

Day Number ____________ Date ____________ Time ____________ Room Number ____________

EVALUATION SHEET

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

Overall Rating of the Room Environment

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

1. Do you have a cold today?

Yes ☐ No ☐

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

_____ hours ago

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

Figure 7. Questionnaire filled out by students and odor panelists.

Table 3. Selected ambient air quality standards and guidelines.[a]

| Contaminant | Agency | Long Term Level | Long Term Averaging Time | Short Term Level | Short Term Averaging Time (hrs) |
|---|---|---|---|---|---|
| Carbon monoxide | EPA | — | — | 40 mg/m$^3$ (35 ppm) | 1 |
| | | | | 10 mg/m$^3$ (9 ppm) | 8 |
| Nitrogen dioxide | EPA | 100 $\mu$g/m$^3$ (50 ppb) | year | — | — |
| Sulfur dioxide | EPA | 80 $\mu$g/m$^3$ (30 ppb) | year | 365 $\mu$g/m$^3$ (140 ppb) | 24 |
| Ozone | EPA | — | — | 240 $\mu$g/m$^3$ (120 ppb) | 1 |
| Hydrocarbons | EPA | — | — | 160 $\mu$g/m$^3$ (250 ppb) | 3[b] |
| Particulates | EPA | 75 $\mu$g/m$^3$ | year | 260 $\mu$g/m$^3$ | 24 |
| Lead | EPA | 1.5 $\mu$g/m$^3$ | 3 mos | — | — |
| Carbon dioxide | OSHA | — | — | 9,000 mg/m$^3$ (5,000 ppm) | 8 |
| | NIOSH | | | 18,000 mg/m$^3$ (10,000 ppm) | 10 |
| Formaldehyde | Europe[c] | — | — | 120 $\mu$g/m$^3$ (100 ppb) | maximum |
| Radon in buildings | EPA[d] & Canada[e] | 0.02 WL (~4 nCi/m$^3$) | year | — | — |

[a]EPA standards for all contaminants except radon are the National Ambient Air Quality Standards; also listed are occupational standards for $CO_2$ and guidelines for formaldehyde and radon in buildings.

[b]6-9 a.m.

[c]Recommended in Denmark, Sweden, West Germany, and the Netherlands

[d]EPA recommendation to the governor of Florida for homes on phosphate lands.

[e]Policy statement by the Atomic Energy Control Board, Canada.

The Classrooms. Table 4 gives the average concentrations of continuously monitored gaseous pollutants in the two test classrooms at each of the three ventilation rates. Outdoor concentrations are also presented for comparative purposes. Inside the classrooms, carbon dioxide was the only gaseous pollutant found in significantly high concentrations; its primary sources were the occupants themselves. Figure 8 shows a profile of the carbon dioxide concentrations during a typical school day. The level of carbon dioxide rose when the students entered the room for the morning and afternoon sessions; it fell at noon and at 3:00 p.m. when the students left the classroom. Daily profiles differed slightly due to variations in classroom occupancy and activity.

Figure 9 presents a histogram of the carbon dioxide concentrations in Room 323 for each ventilation rate. As the quantity of outside air entering the room decreased, there was less "fresh" air to dilute the $CO_2$ generated by the students and as expected, the levels of $CO_2$ increased as the ventilation rate decreased. But even at our lowest ventilation rate (4.4 $m^3$/h or 4.9 cfm per occupant), the average concentration did not exceed 3870 $mg/m^3$ (2150 ppm), as shown in Table 4. (The maximum concentrations of carbon dioxide in the two Rooms 323 and 325 -- 6995 $mg/m^3$ (3890 ppm) and 5760 $mg/m^3$ (3200 ppm), respectively -- also occurred when we were monitoring at our low ventilation rate.) At all three ventilation rates, the concentrations of carbon dioxide in both classrooms were well below the occupational standards of 9000 $mg/m^3$ (5000 ppm) set by OSHA[7] and 18,000 $mg/m^3$ (10,000 ppm) set by NIOSH,[16] both of which refer to a time weighted average for 8 and 10 hour workshifts, respectively. It should be noted, however, that relying on natural infiltration alone when the windows and doors were closed was not sufficient to keep the $CO_2$ at levels considered safe for human health. With the exhaust fans off, the carbon dioxide levels rose from background levels of 684 $mg/m^3$ (380 ppm) to the 9000 $mg/m^3$ (5000 ppm) OSHA standard in less than three hours. This finding supports the computations of the National Bureau of Standards in their study of ventilation requirements of New York City school buildings[17] which concluded that mechanical ventilation should be used when the students are in school classrooms. A ventilation rate of 4.4 $m^3$/h (3 cfm) per occupant was sufficient to keep the carbon dioxide concentrations below 7200 $mg/m^3$ (4000 ppm) at all sites.

The ratios of indoor to outdoor carbon dioxide concentrations in the two classrooms were calculated, and the results for Room 323 are summarized in Figure 10. As shown, the ratio increased as the ventilation rate decreased, indicating that the carbon dioxide was generated indoors and was not being diluted as rapidly at the lower ventilation rates.

Indoor concentrations of the other gaseous pollutants were very low, generally lower than the outdoor levels, and except for nitrogen dioxide in one of the classrooms, they never exceeded the National Ambient Air Quality Standards (NAAQS) promulgated by the Environmental Protection Agency (EPA).[18]

Both sulfur dioxide ($SO_2$) and ozone showed consistently lower indoor than outdoor concentrations. This phenomenon is not unusual, for these reactive gases are primarily generated outdoors and the building

Table 4. Average concentrations of continuously monitored gaseous pollutants at three ventilation rates, Oakland, Gardens Elementary School, NYC.

| Pollutant | Ventilation Rate[a] | Site[b] | | |
|---|---|---|---|---|
| | | Outdoors | Room 323 | Room 325 |
| CO (ppm) | high | 1.5 ± 1.1 | 1.3 ± 1.0 | 1.4 ± 1.0 |
| | intermediate | 1.2 ± 0.7 | 1.1 ± 0.7 | 1.1 ± 0.7 |
| | low | 1.7 ± 1.3 | 7.1 ± 1.3 | 1.7 ± 1.1 |
| $CO_2$ (ppm) | high | 395 ± 51 | 1184 ± 457 | 1259 ± 540 |
| | intermediate | 405 ± 26 | 1750 ± 710 | 1508 ± 532 |
| | low | 413 ± 23 | 2138 ± 745 | 2015 ± 595 |
| $NO_2$ (ppb) | high | 42 ± 16 | 58 ± 12 | 42 ± 14 |
| | intermediate | 48 ± 19 | 55 ± 23 | 41 ± 14 |
| | low | 49 ± 13 | 55 ± 17 | 38 ± 13 |
| NO (ppb) | high | 23 ± 26 | 14 ± 23 | 15 ± 22 |
| | intermediate | 29 ± 26 | 20 ± 26 | 19 ± 23 |
| | low | 50 ± 37 | 47 ± 37 | 48 ± 30 |
| $SO_2$ (ppb) | high | 15 ± 16 | 5 ± 8 | 4 ± 6 |
| | intermediate | 15 ± 8 | 4 ± 3 | 3 ± 2 |
| | low | 23 ± 15 | 5 ± 4 | 4 ± 3 |
| $O_3$ (ppb) | high | 5 ± 6 | 3 ± 7 | 3 ± 2 |
| | intermediate | 3 ± 4 | 2 ± 2 | 2 ± 1 |
| | low | 4 ± 4 | 3 ± 3 | 4 ± 9 |

[a]Ventilation rates:

High: = 14.8 $m^3/h$ (8.8 cfm) per occupant
Intermediate: = 8.2 $m^3/h$ (4.9 cfm) per occupant
Low: = 4.4 $m^3/h$ (2.9 cfm) per occupant

[b]Values for each site are the average concentration and standard deviation of data collected during school hours.

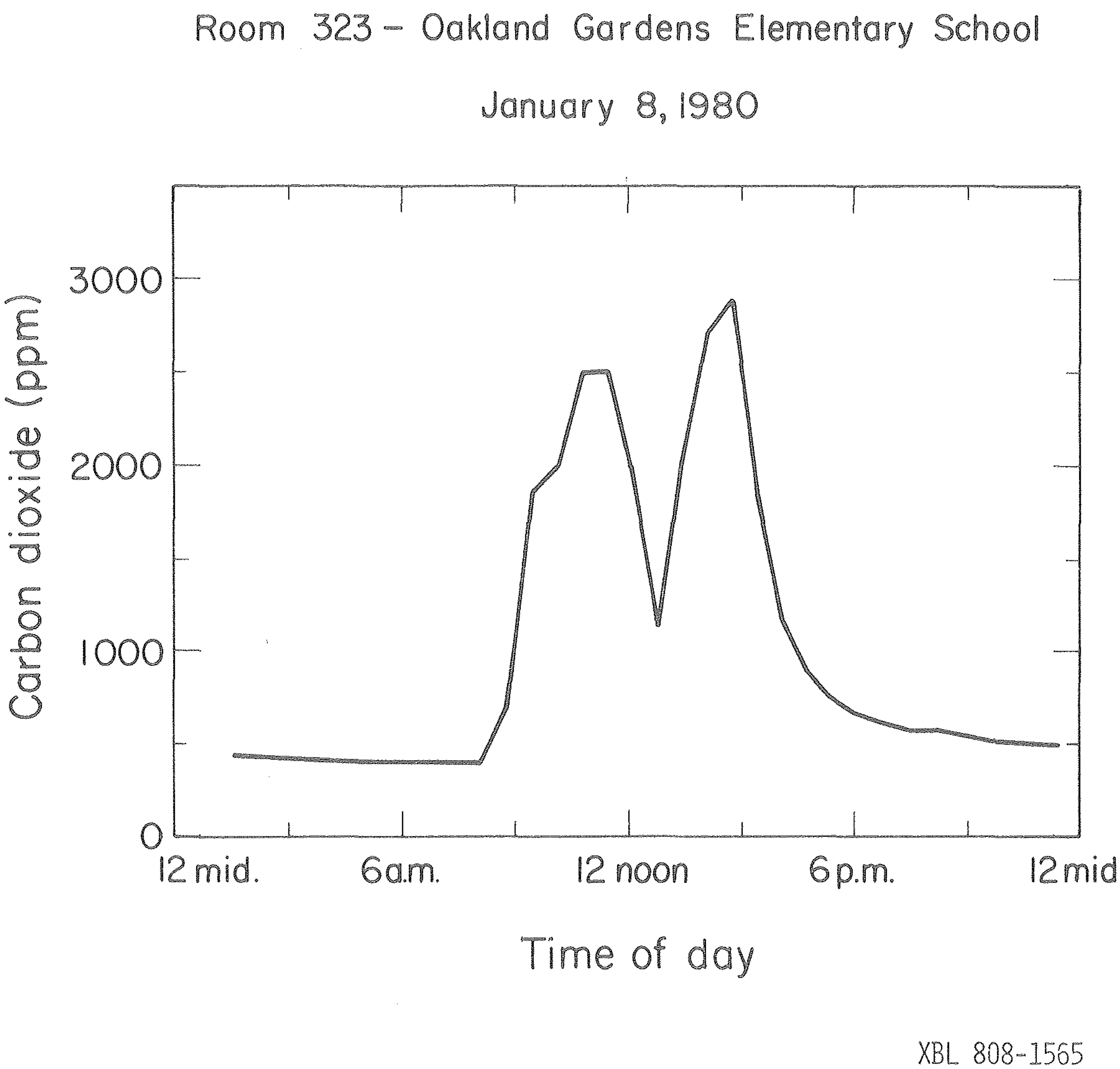


Figure 8. Carbon dioxide levels during a 24-hour period in Room 323.

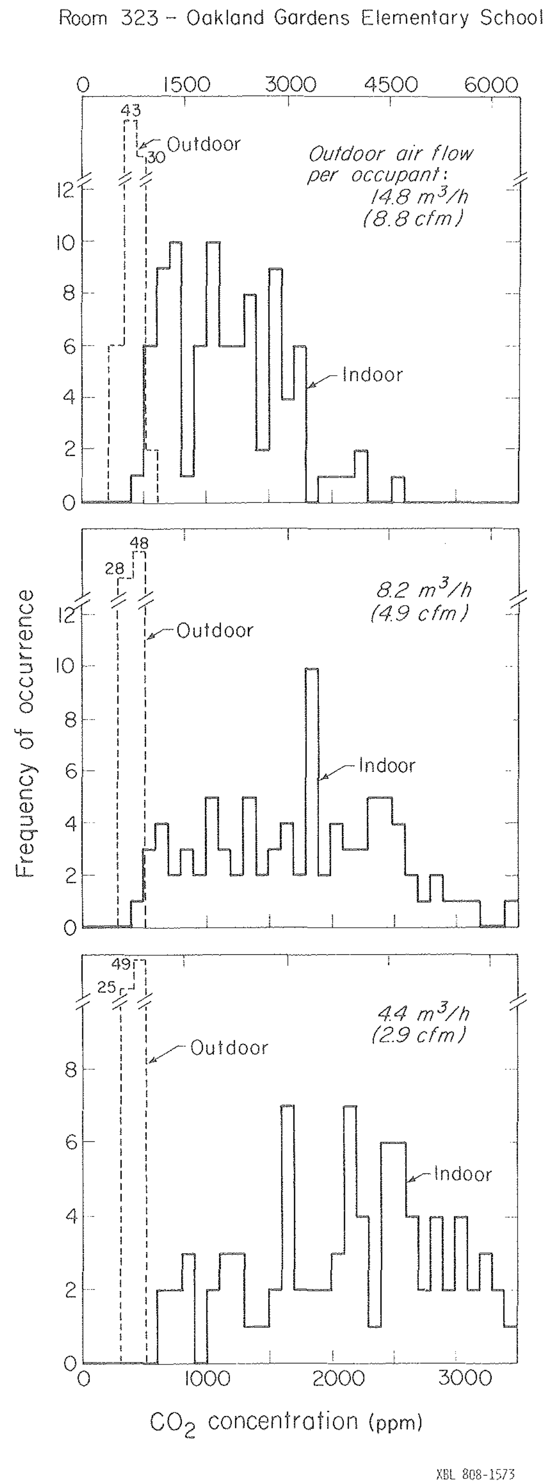


Figure 9. Histograms of indoor and outdoor $CO_2$ concentrations in Room 323 at three ventilation rates.

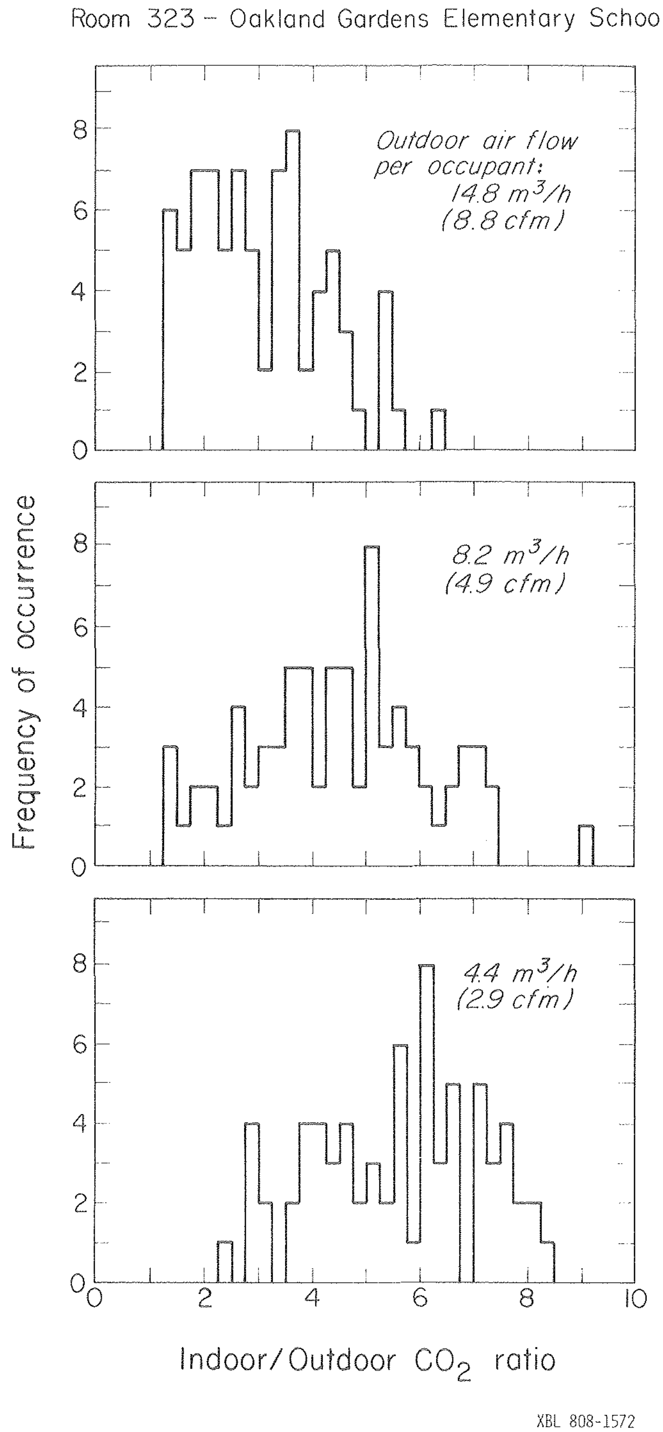


Figure 10. Histograms of the ratio of indoor-to-outdoor $CO_2$ concentrations in Room 323 at three ventilation rates.

envelope often acts as a barrier to their entry. Ozone is produced by a photochemical reaction occurring during the daytime: sulfur dioxide is found in the emissions from automobiles and power plants. The frequency distribution of the $SO_2$ concentrations in Room 325 at the three ventilation rates (see Figure 11) shows that the levels of $SO_2$ were low indoors at the highest ventilation rate, and decreased slightly as the ventilation rate decreased. The maximum indoor concentration was 91 $\mu g/m^3$ (35 ppb) -- well below the EPA ambient air quality standard of 365 $\mu g/m^3$ (140 ppb) for a 24-hour period. Indoor concentrations of ozone were very low; they were too low to observe any change with ventilation rate. All indoor concentrations of ozone were less than 39 $\mu g/m^3$ (20 ppb), well below the one-hour NAAQS for ozone of 240 $\mu g/m^3$ (120 ppb).

The nitrogen oxides are products of combustion. The boiler and kitchen stoves, which are the only combustion sources in the school, are located in the basement. Hence, we did not expect to see high levels of nitrogen oxides inside the classrooms. As shown in Figure 12, the indoor concentrations of nitric oxide (NO) actually increased at the low ventilation rate. This increase was most likely a reflection of the increased outdoor concentrations of NO during the monitoring period at the low ventilation rate. The concentrations of $NO_2$ decreased slightly at the two lower ventilation rates, as seen in Figure 13, but the decrease was not of the same magnitude as the change in ventilation rate. The ratios of indoor-to-outdoor $NO_2$ concentrations, shown in Figure 14, are approximately unity for all ventilation rates, indicating that $NO_2$ is generated outdoors and that indoor concentrations follow changes in the outdoor levels. If a pollutant is generated primarily outdoors and is not very reactive, (such as NO or $NO_2$) we would expect the indoor levels to be similar to outdoor levels at all ventilation rates because the pollutant will not decay once inside the building. In contrast, the concentrations of the reactive pollutant $SO_2$, which is also generated primarily outdoors, decreased as the ventilation rate decreased, because $SO_2$ is likely to react or adsorb on surfaces either upon entering or while inside the building, resulting in lower indoor than outdoor concentrations. (Those instances where indoor/outdoor ratios were high generally correlated with high odor levels or with the use of cleaning solutions in the hallway, and may be due to interferences from ammonia and organonitrogen compounds that are encountered in the chemiluminescence method of analyzing nitrogen oxides.)

The EPA ambient air quality standard for $NO_2$ is 100 $\mu g/m^3$ (50 ppb) for a one-year period; there is no short term standard. The average outdoor concentration of $NO_2$, as indicated in Table 4, was very close to this standard. $NO_2$ levels in Room 325 were similar to or slightly lower than the outdoor levels at the three ventilation rates. In Room 323 the average concentration of $NO_2$ was slightly higher than outdoor levels and exceeded the one-year EPA ambient air quality standard during the high and intermediate ventilation rates by 5 and 8 ppb, respectively. We have no explanation why the $NO_2$ levels were higher in Room 323 than the outdoor or Room 325 levels other than the fact that ammonia cleaning solutions were often used in the adjoining student restrooms. The restrooms doors were always open to the hallway and higher $NO_2$ levels in the adjacent Room 323 and the hallway could be caused by the interference of ammonia mentioned above. We feel, however, that the large standard

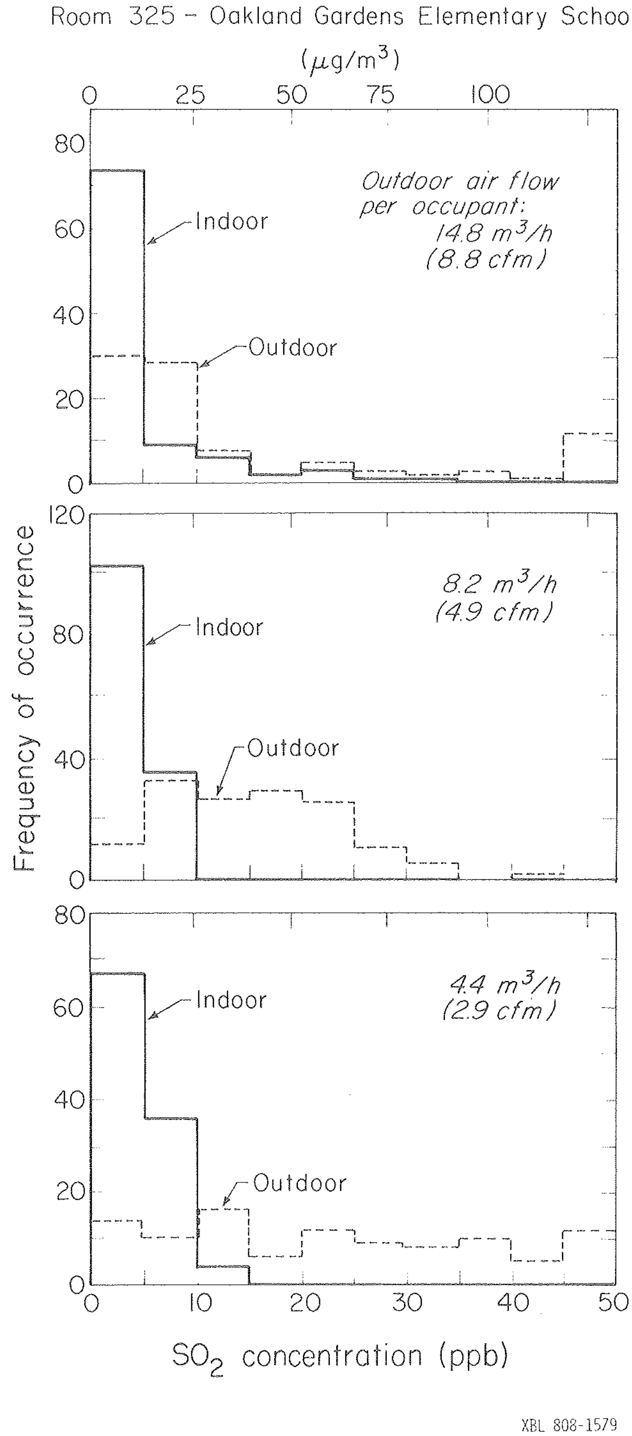


Figure 11. Histograms of indoor and outdoor $SO_2$ concentrations in Room 325 at three ventilation rates.

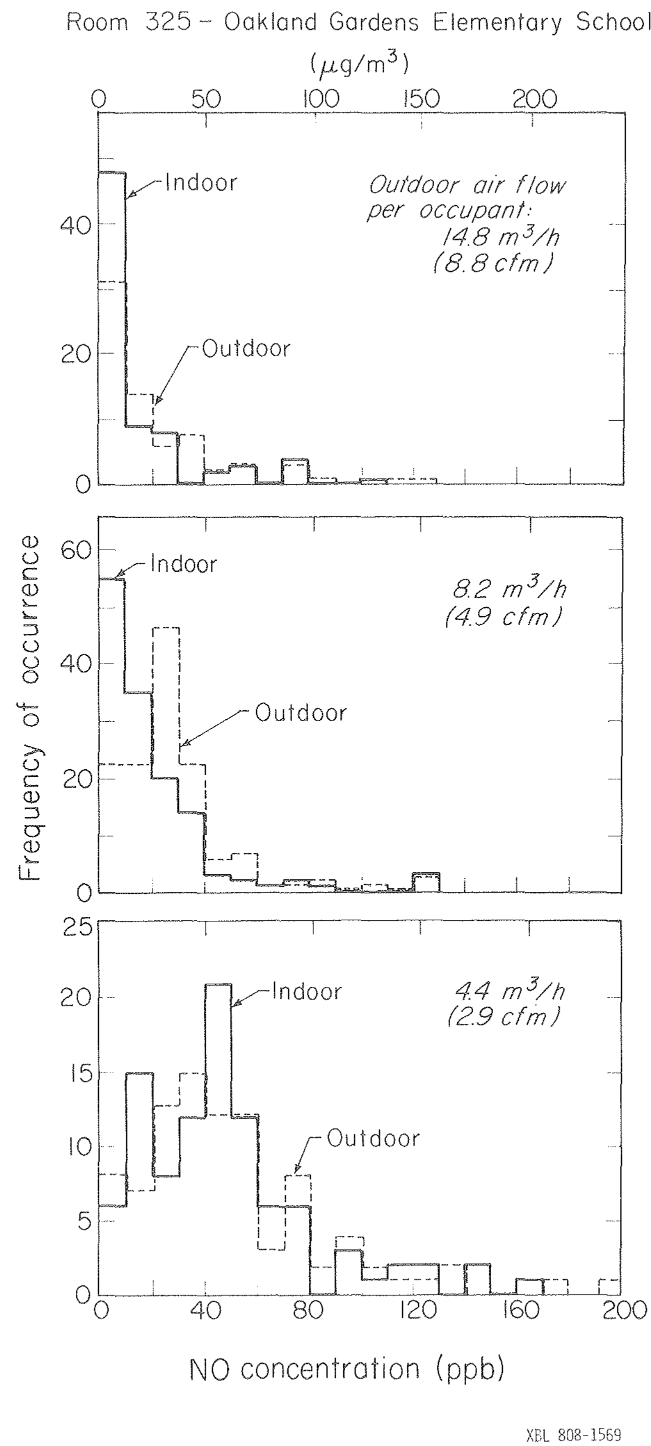


Figure 12. Histograms of the indoor and outdoor NO concentrations in Room 325 at three ventilation rates.

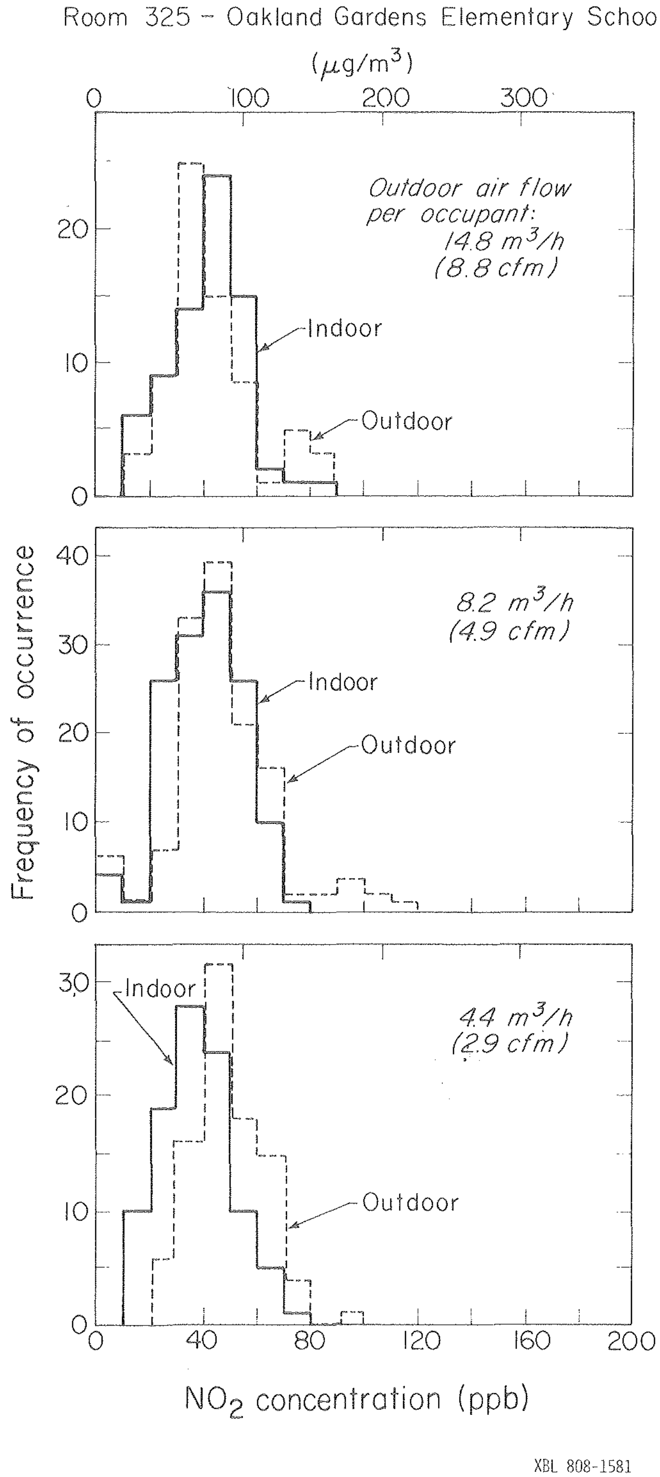


Figure 13. Histograms of the indoor and outdoor $NO_2$ concentrations in Room 325 at three ventilation rates.

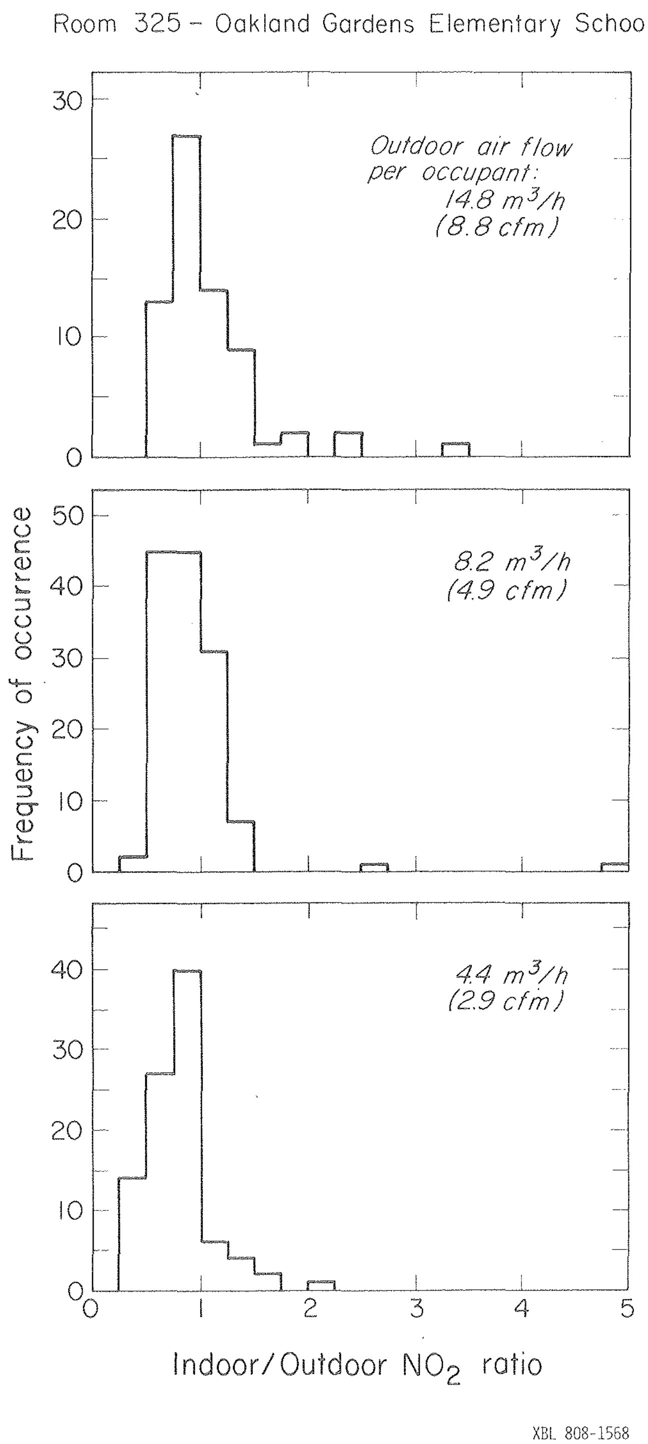


Figure 14. Histograms of the ratios of indoor-to-outdoor $NO_2$ concentrations at three ventilation rates.

deviation indicates that an average concentration that slightly exceeded the NAAQS (by 5-8 ppb) is not significant.

The average concentrations of carbon monoxide (CO) at each of the three ventilation rates were less than 10.4 $mg/m^3$ (1.7 ppm). Outdoor levels were approximately the same. Carbon monoxide is produced from incomplete combustion of fossil fuels. Since there were no combustion sources inside the classrooms, it is not surprising that only very low levels were measured. The NAAQS for CO for a one-hour period of 40 $mg/m^3$ (35 ppm) was never exceeded. The maximum measurement -- 10.4 $mg/m^3$ (9 ppm) -- was recorded one time in Room 323 in the morning and was probably from outdoor air containing CO generated by cars during the early commute hours.

The measurements of formaldehyde and total aldehydes that were taken for approximately five weeks in Room 323 showed very low concentrations at all three ventilation rates, with no significant difference from one ventilation rate to another. The average indoor formaldehyde concentration was 22 ± 11 $\mu g/m^3$ (18 ± 9 ppb); the outdoor concentration was 13 ± 1 $\mu g/m^3$ (11 ± 6 ppb). The average indoor concentration of total aldehydes, expressed as equivalents of formaldehyde, was 32 ± 24 $\mu g/m^3$ (27 ± 20 ppb): the outdoor concentration was 17 ± 18 $\mu g/m^3$ (14 ± 15 ppb). These concentrations were well below the guidelines recommended or proposed in several European countries of 120 $\mu g/m^3$ (100 ppb).[19,20,21]

The concentrations of radon measured in Room 325 and in the boiler room in the basement of the school were less than 1 $nCi/m^3$. These concentrations are below the .02 WL (approximately 4 $nCi/m^3$) recommended by the Atomic Energy Control Board of Canada[22] and by the EPA to the governor of the state of Florida for homes built on phosphate reclaimed lands.[23]

The Hallway. Table 5 presents the average and maximum concentrations of gaseous pollutants in the hallway. Since the ventilation rate in the hallway was neither measured nor changed in any way, the averages listed in Table 5 include all the data collected during school hours for the entire seven-week sampling period for both outdoors and hallway. When compared to the average concentrations found in the classrooms (Table 4), it is evident that there is little difference between the hallway and the two classrooms monitored. The concentration of all pollutants, except $NO_2$, were less than the EPA ambient air quality standards. $NO_2$ levels were 103 $\mu g/m^3$ (55 ± 17 ppb), slightly higher than the one-year EPA standard for outdoor air, but considering outdoor levels and possible interferences from ammonia and the large standard deviation, these levels are not considered significant.

Summary of Gaseous Contaminants. Of the common inorganic gaseous pollutants measured, only carbon dioxide was seen in significantly high concentrations inside the school; however, even at the low ventilation rate of 4.4 $m^3/h$ (3 cfm) per occupant, $CO_2$ concentrations did not exceed current occupational standards. The indoor concentrations of carbon monoxide, sulfur dioxide, ozone, nitric oxide, formaldehyde, and radon were also lower than the relevant ambient air quality standards. In one

Table 5. Average and maximum concentrations of gaseous pollutants in the hallway during school hours, Oakland Gardens Elementary School, NYC.

| Gas (unit) | Average Concentration[a] | | Maximum Concentration[b] | |
|---|---|---|---|---|
| | Hallway | Outdoors | Hallway | Outdoors |
| CO (ppm) | 1.6 ± 1.1 | 1.4 ± 1.0 | 8-10 | 6-8 |
| $CO_2$ (ppm) | 1491 ± 492 | 404 ± 37 | 2900-3000 | 500-600 |
| $SO_2$ (ppb) | 3 ± 3 | 17 ± 14 | 20-25 | 87 |
| $O_3$ (ppb) | 3 ± 2 | 4 ± 5 | 10-20 | 20-30 |
| $NO_2$ (ppb) | 55 ± 17 | 47 ± 17 | 120-130 | 110-120 |
| NO (ppb) | 31 ± 33 | 34 ± 32 | 228 | 231 (149)[c] |

[a]Values given are average concentrations and standard deviations of the gases for the data collected during school hours.

[b]If one value was much higher than others, this value is given. Otherwise, a range of the maximum values measured is given. The maximum outdoor concentrations do not necessarily correspond to the times of maximum indoor concentrations.

[c]Outdoor NO concentration at the time of maximum hallway NO concentration.

of the classrooms and the hallway, the indoor concentrations of nitrogen dioxide slightly exceeded the one-year EPA standard for outdoor air.

Particulates

Particulates were measured in Room 323, the hallways and outdoors and the results are displayed as daily bar graphs. The data on fine particulates (those with a diameter less than 2.5 microns) are displayed separately. The fine particulates are of special interest because they have a high probability of reaching the lungs and bronchial passages, whereas coarse particulates, which have a diameter between 2.5 and 15 microns, tend to be filtered out by the nasal passages. The data called "total inhalable particulates" is the sum of the fine and coarse fractions and is the total mass of particulates with diameters less than 15 microns. Even though the EPA ambient air quality standard for particulates is promulgated for "total suspended particulates" (TSP), which refer to all particulate mass suspended in the air including particulates of diameter greater than 15 microns, we will compare the TSP standard with the total inhalable particulates measured in the school.

Average concentrations of particulate mass have been calculated for school days only in order to indicate the levels that the students are exposed to on a daily basis.

Room 323. The measurements of fine and total inhalable particulates in Room 323 are summarized in Figure 15. As shown, the concentration of the fine particulate mass outdoors was usually higher than that indoors except for one day when the fine particulate mass indoors was almost twice the outdoor concentration. The fine particulate mass indoors ranged from 8 to 56 $\mu g/m^3$ (average = 22 $\mu g/m^3$) and constituted approximately 45-50% of the total mass. The fine particulate mass outdoors was slightly higher, ranging from 11 to 55 $\mu g/m^3$ (average = 28 $\mu g/m^3$), and was approximately 70-75% of the total mass, a much larger percentage than seen indoors. Indoor concentrations of total inhalable particulates were sometimes higher than outdoor levels, but there did not appear to be any correlation between these variations. On the average, however, the indoor concentration of total inhalable particulates (58 $\mu g/m^3$) was higher than average outdoor levels (37 $\mu g/m^3$).

Table 6 lists the average concentrations of the particulate mass at each ventilation rate. As shown, the changes in ventilation rate did not seem to effect the concentrations of the particulate mass. A much longer sampling period would be required to determine accurately whether or not levels of fine particulate mass are, in fact, influenced by changes in ventilation rate. The concentrations of total inhalable particulates in Room 323 were significantly higher than outdoor levels at all three ventilation rates. The coarse particulate fraction indoors was much higher than that found outdoors. The particulates were probably being generated indoors and the variation in concentrations did not depend on the ventilation rate but rather on the student activity during the day.

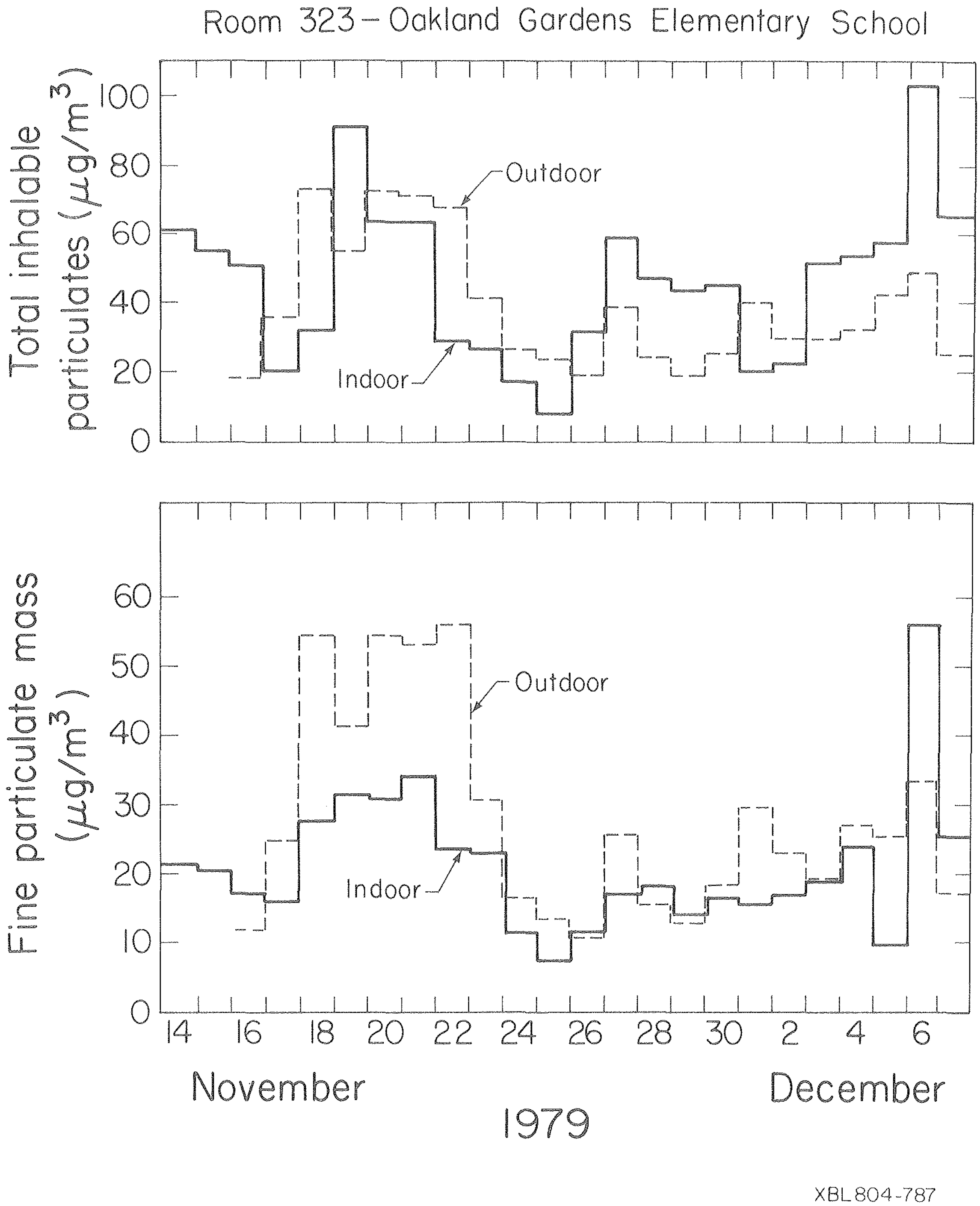


Figure 15. Comparison of particulate mass in Room 323 and outdoors.

Table 6. Average concentrations and standard deviations of particulate mass during school days, Room 323, Oakland Gardens Elementary School, NYC.

| | Fine Particulate Mass (<2.5 μm) | | |
|---|---|---|---|
| Ventilation rate[a] | Room 323 (μg/m$^3$) | Outdoors (μg/m$^3$) | Ratio[b] |
| High | 25 ± 16 | 24 ± 70 | 1.04 ± .45 |
| Intermediate | 20 ± 60 | 36 ± 22 | 0.82 ± .67 |
| Low | 19 ± 90 | 24 ± 18 | 0.93 ± .25 |

| | Total Inhalable Particulates (<15 μm) | | |
|---|---|---|---|
| Ventilation rate[a] | Room 323 (μg/m$^3$) | Outdoors (μg/m$^3$) | Ratio[b] |
| High | 61 ± 21 | 35 ± 10 | 1.85 ± 0.53 |
| Intermediate | 65 ± 15 | 49 ± 27 | 1.79 ± 1.0 |
| Low | 48 ± 13 | 34 ± 22 | 1.69 ± 0.56 |

[a]Ventilation rates:
High = 14.8 m$^3$/h (8.8 cfm) per occupant
Intermediate = 8.2 m$^3$/h (4.9 cfm) per occupant
Low = 4.4 m$^3$/h (2.9 cfm) per occupant

[b]The Room 323/outdoor ratios were calculated for each day and values given represent the average of the ratios.

The National Ambient Air Quality Standards (NAAQS) for TSP for a one-year period is 75 $\mu g/m^3$; the 24-hour standard is 240 $\mu g/m^3$. The average concentration of total inhalable particulates in Room 323 was 58 $\mu g/m^3$, which is less than the one-year NAAQS for TSP. The maximum concentration recorded for any single day (101 $\mu g/m^3$) was also well below the NAAQS for TSP of 240 $\mu g/m^3$ for a 24-hour period.

Hallway. In contrast to Room 323, the concentrations of both fine and total inhalable particulates in the hallway, as shown in Figure 16, were higher than the outdoor levels. Days when the hallway concentrations were similar to the outdoor levels were usually weekends or holidays when there was no activity indoors. These elevated indoor levels were probably caused by students congregating in the hallway on their way to other activity rooms and by the fact that doors to other classrooms were left open to the hallway. Both situations would generate more particulates or stir up existing particulates.

Table 7 shows that the average concentration of total inhalable particulate mass in the hallway was five times the outdoor level; the fine particulate mass was approximately twice the outdoor concentration. The maximum 24 hour sample was 198 $\mu g/m^3$, which is approximately 80% of the NAAQS for TSP for a 24-hour period. For the data collected during school days, the average of 145 $\mu g/m^3$ for total inhalable particulates in the hallway is almost twice the NAAQS for a one-year average.

Elemental Analysis. The elemental analysis of the particulates by X-ray fluorescence revealed only trace amounts of most of the twenty-eight elements measured in Room 323 and the hallway. In the fine particulate fraction, only sulfur, lead, and bromine were found in concentrations above the level of detectability. In the coarse fraction, only sulfur was measurable. Most of the mass was probably carbon, hydrogen, nitrogen and oxygen which are not detected by X-ray analysis. Figures 17, 18, and 19 show the daily concentrations of fine particulate sulfur, lead, and bromine in Room 323 and outdoors. As shown, the outdoor concentrations usually were higher than the indoor levels. Table 8 shows the average and maximum concentrations of these three elements at all three sites monitored. The data showed no differences when separated by ventilation rate. In Room 323 the average concentrations of all three elements were approximately half the outdoor levels. The average concentration of fine particulate sulfur for Room 323 was 2.5 $\mu g/m^3$ (the maximum 24-hour measurement was 9.8 $\mu g/m^3$). Since most of the elemental sulfur is assumed to be in the form of sulfates, this concentration represents an average of approximately 7.5 $\mu g/m^3$ as sulfate. The hallway concentrations were higher than outdoor levels, following the trend of particulates in the school.

Of the three elements, only lead, which is associated with automobile exhaust, is included in the NAAQS by the EPA. The NAAQS for lead is 1.5 $\mu g/m^3$ for a three-month period (any calendar quarter). For the four-week sampling period, the average indoor concentrations were less than 1.3 $\mu g/m^3$. The average of the concentrations of lead at all three sites monitored were lower than the NAAQS, although in the hallway the value was exceeded during several 24-hour periods.

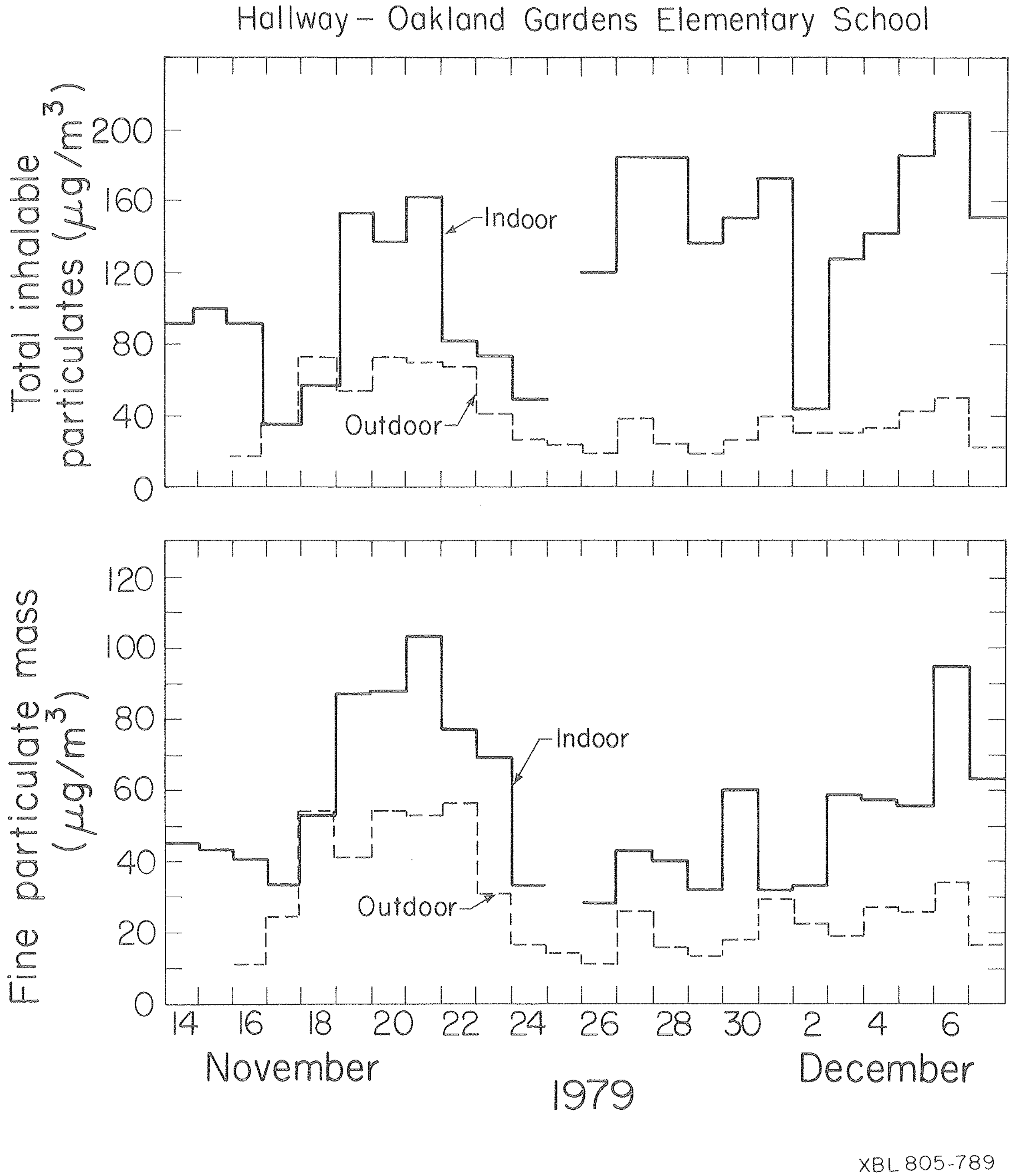


Figure 16. Comparison of particulate mass in the hallway and outdoors.

Table 7. Average concentrations and standard deviations of particulate mass during school days in the hallway, Oakland Gardens Elementary School, NYC.

| | Fine Particulate Mass[a] (μg/m$^3$) | Total Inhalable Particulates[b] (μg/m$^3$) |
|---|---|---|
| Hallway | 59 ± 20 | 145 ± 340 |
| Outdoors | 26 ± 15 | 37 ± 190 |
| Ratio[c] | 2.5 ± .7 | 4.9 ± 1.9 |

[a]Less than 2.5 microns

[b]Less than 15 microns

[c]The hallway/outdoors ratios were calculated for each day and values given represent the average of the ratios.

Table 8. Average and maximum concentrations of fine particulate sulfur, lead, and bromine during school days, Oakland Gardens Elementary School, NYC.

| Element | Room 323 | | Outdoors | | Hallway | |
|---|---|---|---|---|---|---|
| | Average[a] | Max. | Average[a] | Max. | Average[a] | Max. |
| Sulfur (μg/m$^3$) | 2.7 ± 2.0 | 9.80 | 3.2 ± 1.5 | 6.90 | 6.3 ± 3.6 | 14.1 |
| Lead (μg/m$^3$) | 0.5 ± 0.3 | 1.03 | 1.2 ± 1.0 | 3.35 | 1.3 ± 1.0 | 3.53 (4.23)[b] |
| Bromine (ng/m$^3$) | 141 ± 93 | 364 | 395 ± 398 | 1324 | 378 ± 366 | 1209 (1350)[b] |

[a]Average concentrations ± one standard deviation

[b]Maximum mass on weekends or holidays (higher than maximum mass on school days)

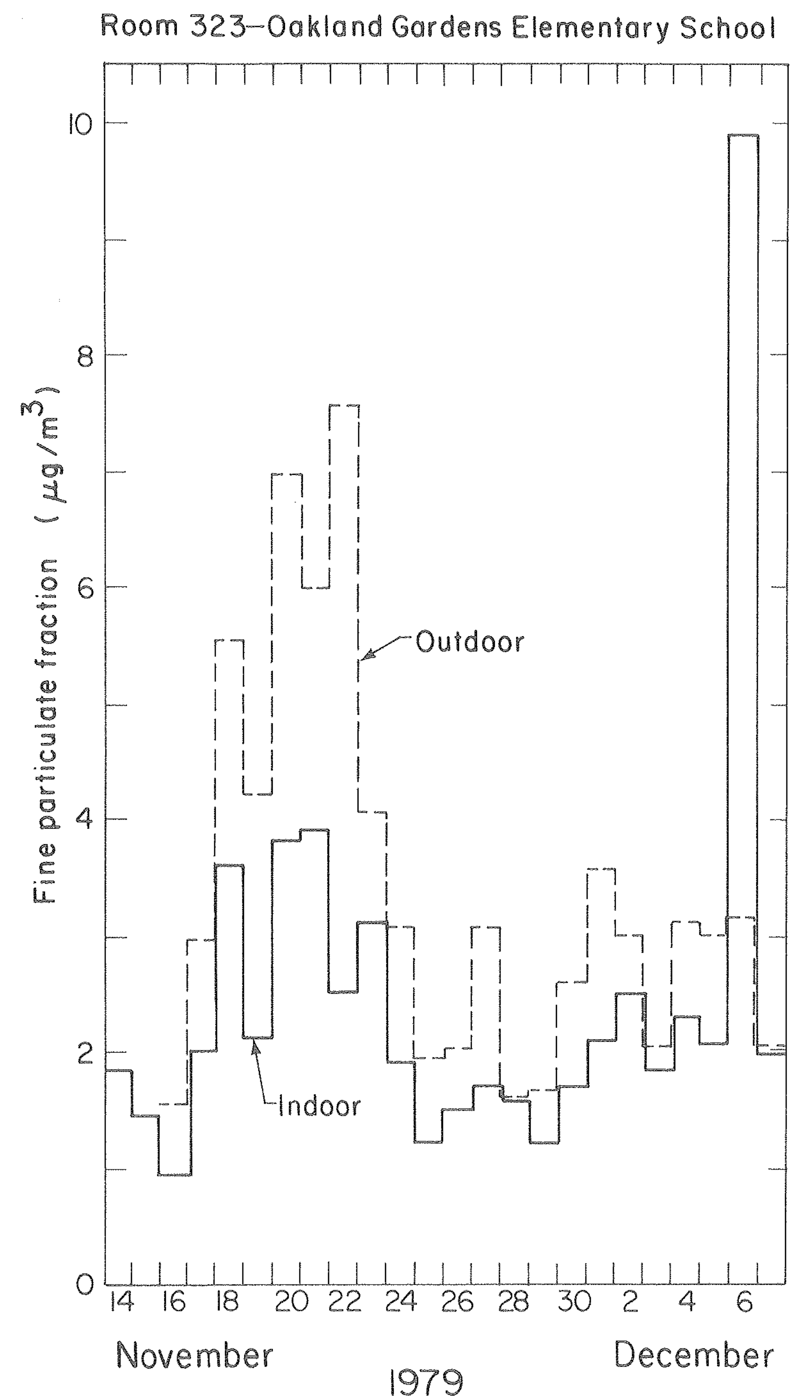


Figure 17. Comparison of the mass of fine particulate sulfur in Room 323 and outdoors.

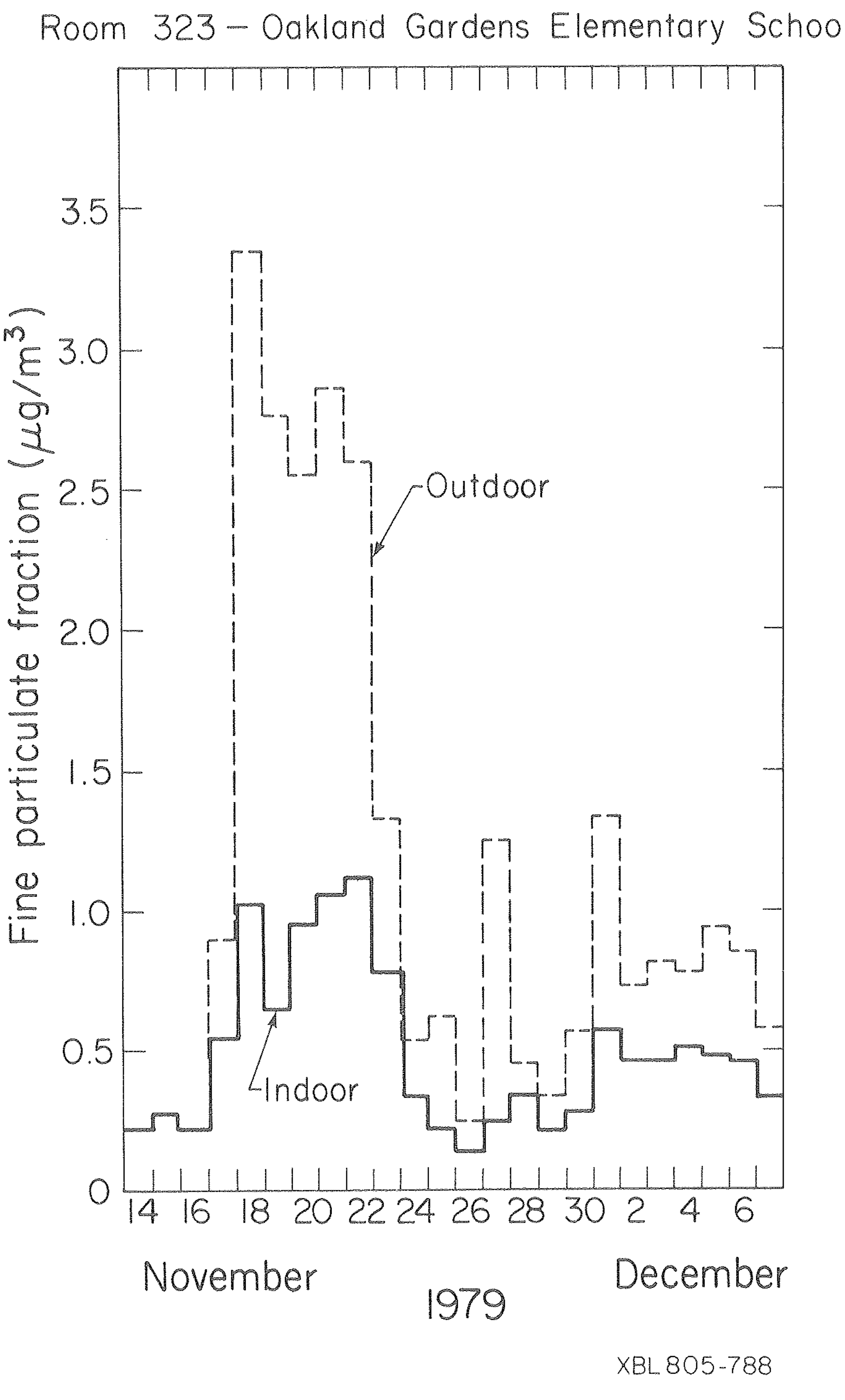


Figure 18. Comparison of the mass of fine particulate lead in Room 323 and outdoors.

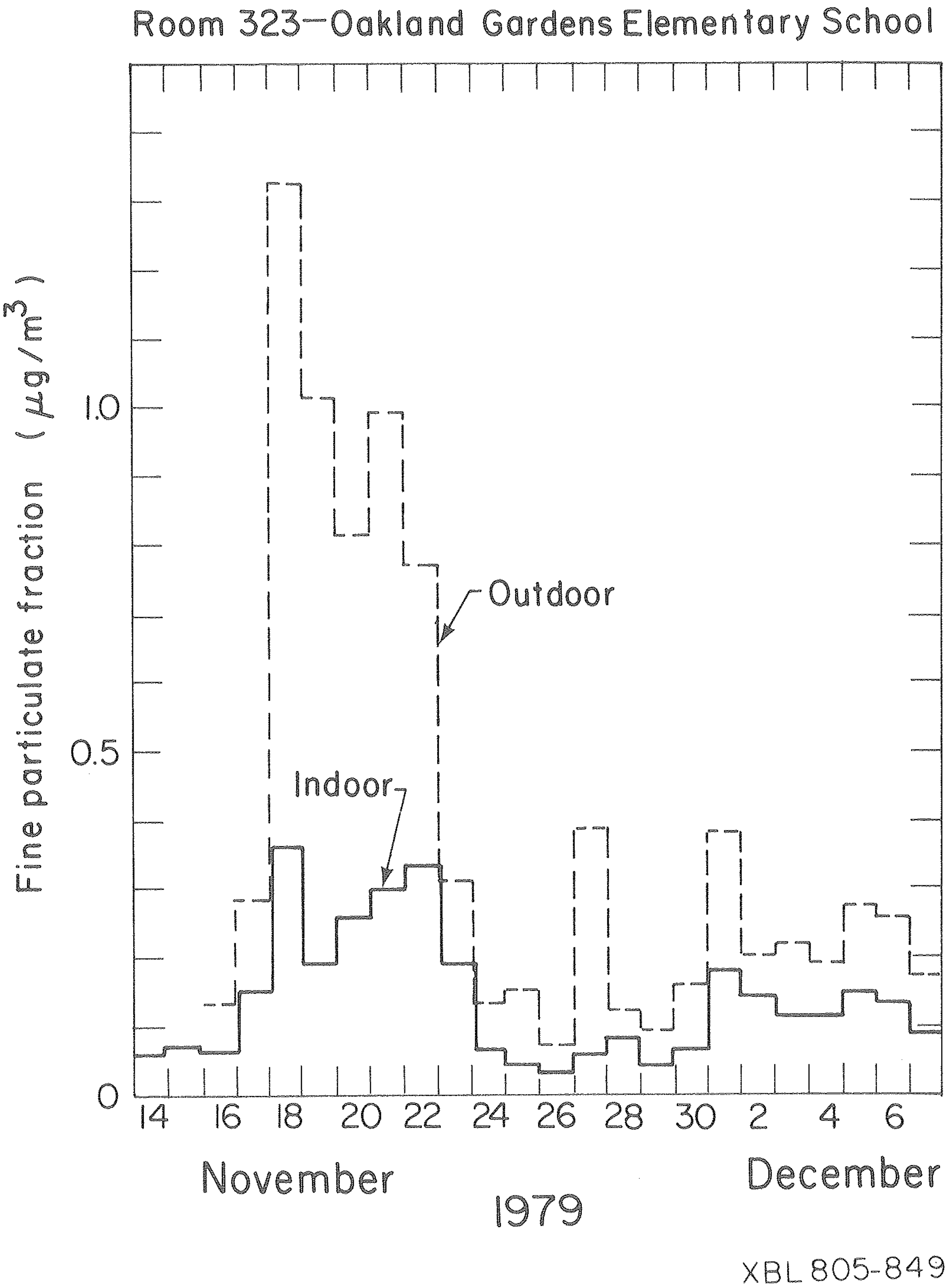


Figure 19. Comparison of the mass of fine particulate bromine in Room 323 and outdoors.

Odor Perception

The Oakland Gardens Elementary School was the second site visited by TRC as part of its field monitoring program to determine ventilation requirements for controlling odors in buildings.[24] The sensory perception of odors, odor acceptability, and the chemical (organic) composition of indoor air were studied for a two-week period with the ventilation system in the high and low operating modes.

Table 9 summarizes the results of measurements of odor dilution ratio, odor intensity, and odor acceptability in the two test rooms (Rooms 323 and 325) and of acceptability measurements in a control room where no changes were made in the ventilation rate (Room 322). Under high ventilation conditions, the $ED_{50}$ for outside and inside air were quite similar (4.3 and 4.1 respectively). In the low ventilation mode, the $ED_{50}$ increased by approximately 50% in the two classrooms and outdoors. Similar results were obtained from the odor intensity measurement, i.e., a small increase in intensity with decreasing ventilation rate.

Both occupants and panelists judged odor acceptability. Table 9 shows the odor acceptability as perceived by the panelists under high and low ventilation rates. The acceptability range of the high ventilation condition was 75-86% by the panelists. The control room (Room 322), where the ventilation rate was lower than the two test rooms, was judged to be the least acceptable. Under the low ventilation conditions, the acceptance was lower in all three rooms, 49-68%. Note that although no change in ventilation was made in the control room, the odor acceptability by the panelists dropped from 75 to 51%. During the testing under the low ventilation rate, the outdoor air also increased in odor perceptability, the $ED_{50}$ increasing by approximately 50 %. The uncertainty in these odors measurements is high (15-20 %). It is difficult to determine if the decrease in odor acceptability in the classrooms was due to a decrease in ventilation rate or from the fact that the outdoor air and indoor air in adjacent rooms had a higher odor content.

According to the section of ASHRAE Standard 62-73 pertaining to the odor acceptability of outdoor air, at least 60% of a panel of no fewer than 10 untrained observers must agree that the air is free of objectionable odors. If this standard were applied to indoor air, the odor levels in the three classrooms would be acceptable under the high ventilation conditions. Under the low ventilation conditions, however, the odor levels would be unacceptable in two of the three classrooms monitored, (one of the test classrooms and the control room). It should be noted that the "low" ventilation rate was only 4.4 $m^3/h$ (3 cfm) per occupant, which is less than the present ASHRAE minimum. Criteria for indoor air quality with respect to odor levels are now being developed by ASHRAE for Standard 62-73R. One of the changes being proposed is that at least 80% of a panel of no fewer than 20 untrained observers must agree on the acceptability of the air quality as regards odor. Based on the responses of only 10 untrained observers and considering that 80% of this panel must agree on the odor acceptability, the odor level was acceptable in two of the three classrooms under the high

Table 9. Summary of data on odor perception by the panelists of air samples outdoors and from three classrooms under high and low ventilation rates at Oakland Gardens Elementary School, NYC.

| | Odor Dilution Ratio ($ED_{50}$) | | Odor Intensity Butanol Scale | | Average Acceptability | |
|---|---|---|---|---|---|---|
| | High Vent. | Low Vent. | High Vent. | Low Vent. | High Vent. | Low Vent. |
| Room 323 | | | | | | |
| A.M. | 3.3 | 6.8 | 1.6 | 2.4 | | |
| P.M. | 4.4 | 6.1 | 1.6 | 2.1 | | |
| Average | 3.9 | 6.5 | 1.6 | 2.3 | 82 | 68 |
| Room 325 | | | | | | |
| A.M. | 3.6 | 7.5 | 1.5 | 2.2 | | |
| P.M. | 5.0 | 3.5 | 1.4 | 2.2 | | |
| Average | 4.3 | 5.5 | 1.4 | 2.2 | 86 | 49 |
| Room 322 (Control Room) | | | | | | |
| Average | - | - | - | - | 75[a] | 52[a] |
| Outdoors | | | | | | |
| Average | 3.2 | 4.8 | 1.6 | 2.1 | - | - |

[a]Ventilation rate was unchanged for the control room. See discussion on odor perception.

ventilation conditions of 15.2 $m^3$/h (9 cfm) per occupant. The "unacceptable" classroom was the control classroom which had an infiltration rate of less than 1.7 $m^3$/h (1 cfm) per occupant because the exhaust fans were not used. At the low ventilation rate (4.4 $m^3$/h or ~3 cfm per occupant), none of the classrooms would have been acceptable. Because of the large uncertainty in the measurements of odor perception, these results indicate that at least 20 panelists and longer testing periods should be used.

Odorant concentrations were too low to allow specific chemical identification by gas chromatographic-odorogram analysis.

## ENERGY SAVINGS

Since Oakland Gardens Elementary School operated under conditions with the exhaust fans off and this ventilation rate was too low to maintain adequate air quality, a reduction in energy consumption through a reduced ventilation rate by turning off the exhaust fans is not feasible in this school. Therefore, we have computed potential energy savings achievable by reducing the ventilation rate for an elementary school of similar size to Oakland Gardens Elementary School but operating with a ventilation rate in the classrooms of 25.3 $m^3$/h (15 cfm) per occupant, the recommended ASHRAE value.

If a similar elementary school averaged 35 students in each of its 36 classrooms, there would be a total of 1260 students. A reduction in ventilation rate from 25.3 to 8.9 $m^3$/h (15 to 5 cfm) per occupant would then be 16.8 $m^3$/h (10 cfm) per occupant and result in a total reduction of 20,678 $m^3$/h (12260 cfm).

To determine the yearly ventilation-heating load for the climate of New York City, we used previous calculations of ventilation heating load[25] in various locations of the United States. Oakland Gardens Elementary School is located in a 2722 degree-day base 18.3°C (4900 degree-day, base 65°F) climate. For the 9 A.M. to 5 P.M. period over a full heating season, 0.031 gigajoules (50,000 Btu) is required to heat each $m^3$/h (cfm) of outside air to an indoor temperature of 21 °C (70°F). Assuming a heating system efficiency of 0.65, we calculate the energy savings as shown below.

$$\text{Energy Savings} = \frac{\text{(Vent. heating load)(Vent. rate reduction)}}{\text{(Heating system efficiency)}}$$

$$= \frac{.031 \ \frac{\text{GJ}}{\text{m}^3/\text{h}} \ (21{,}269 \ \text{m}^3/\text{h})}{0.65}$$

$$= 1014 \ \text{GJ} \quad (9.61 \times 10^8 \ \text{Btu})$$

Considering that the No. 6 heating oil used in the New York City schools has 1.53 X $10^5$ Btu/gallon, this energy represents 6278 gallons of heating oil. At a cost of 85 cents per gallon, the energy cost savings would be approximately $5335 per year for an elementary school similar in size to Oakland Gardens Elementary School with approximately 1260 students and a ventilation rate of 25.3 $m^3$/h (15 cfm) per occupant. This amount represents the savings which would be realized from a ventilation reduction in classrooms only. A much higher amount would be saved by reducing ventilation not only in classrooms but in the entire school, including activity rooms such as the lunchroom, gymnasium, and auditorium.

## CONCLUSIONS

In this study of indoor air quality at Oakland Gardens Elementary School, the only air quality problems encountered were high levels of particulates in the hallway (but not in the individual classrooms), nitrogen dioxide levels both indoors and outdoors that were close to or slightly exceeding EPA ambient air quality standards, and a decrease in odor acceptability (to <60%) in one of the classrooms at the "low" ventilation rate of 4.4 $m^3$/h (3 cfm) per occupant. Only the deterioration of odor acceptability can be attributed to a reduction in ventilation rate. The small number of panelists used and the large uncertainty in the odor measurements make the odor data difficult to assess. The levels of the other gaseous pollutants and of particulates in the classrooms were below relevant air quality standards even at the "low" ventilation rate of 4.4 $m^3$/h (3 cfm) per occupant.

We conclude that the ventilation rate can be reduced to the "intermediate" ventilation rate of 8.4 $m^3$/h (5 cfm) per occupant without any significant deterioration of the air quality indoors and without adverse effects on the health, safety, and comfort of the occupants. 8.4 $m^3$/h (5 cfm) per occupant is the new ASHRAE 62-81 requirements for school classrooms where smoking is not allowed (or approximately one-half the older ASHRAE recommendations for this school from ASHRAE 62-73). Mechanical ventilation (exhaust fans on) is required in this school to maintain carbon dioxide levels below 9000 mg/$m^3$ (5000 ppm). Our calculations indicate that moderate savings in energy costs can be achieved through a reduction in ventilation rate for schools (similar to Oakland Gardens Elementary School) currently operating with a ventilation rate in the classrooms of 25.3 $m^3$/h (15 cfm) per occupant. These results corroborate the findings of our field studies at Carondelet High School in California[5] and at Fairmoor Elementary School in Ohio.[6]

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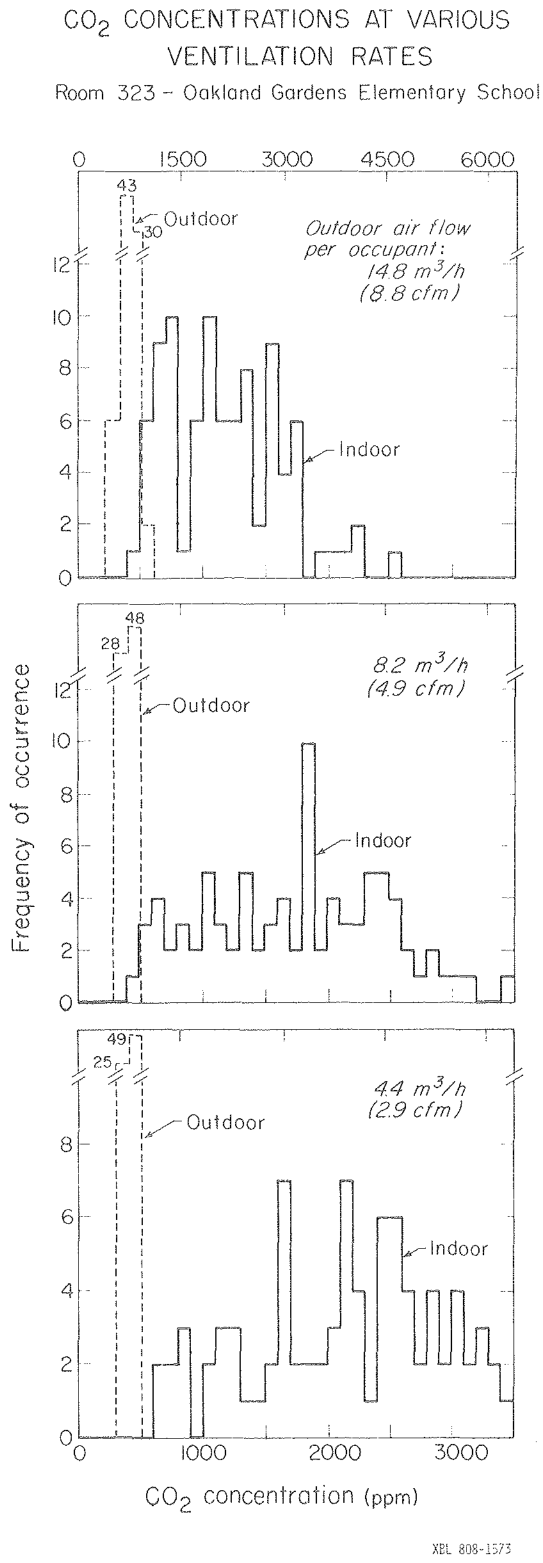
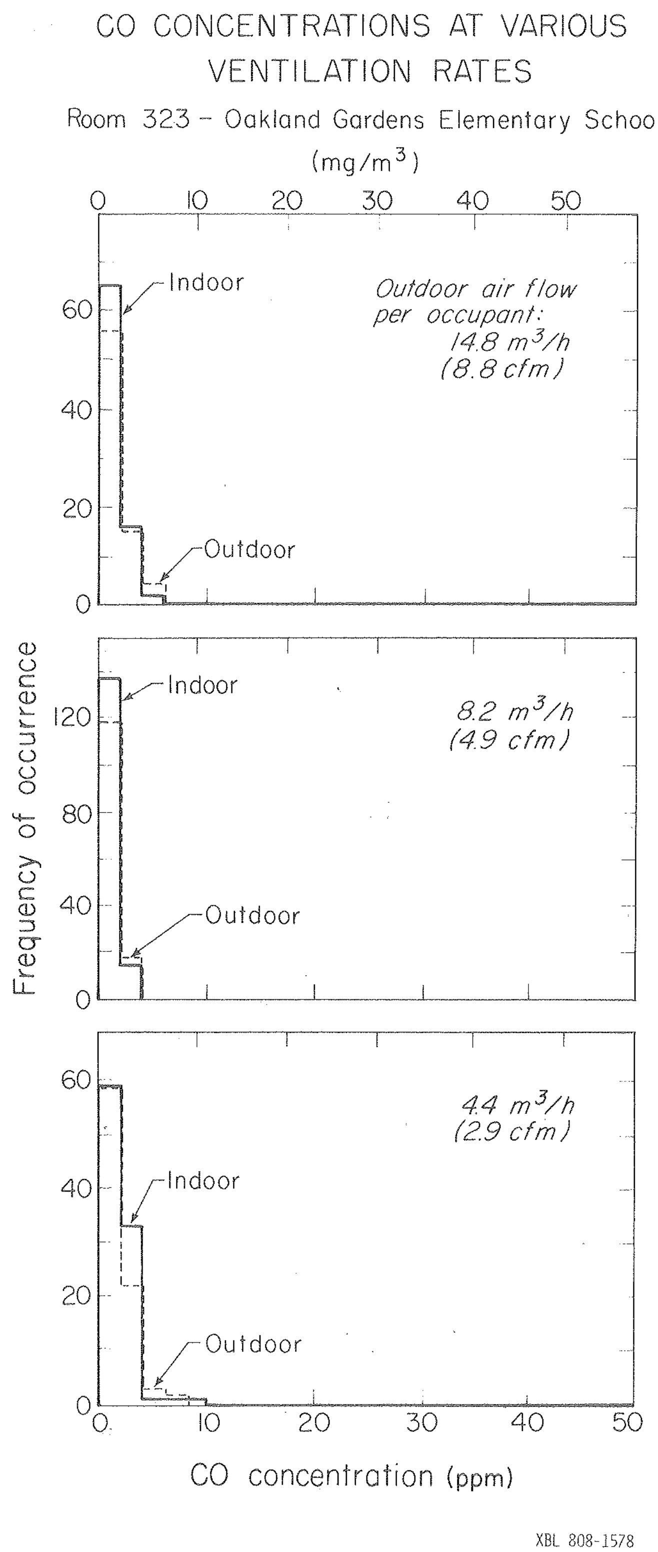
APPENDIX

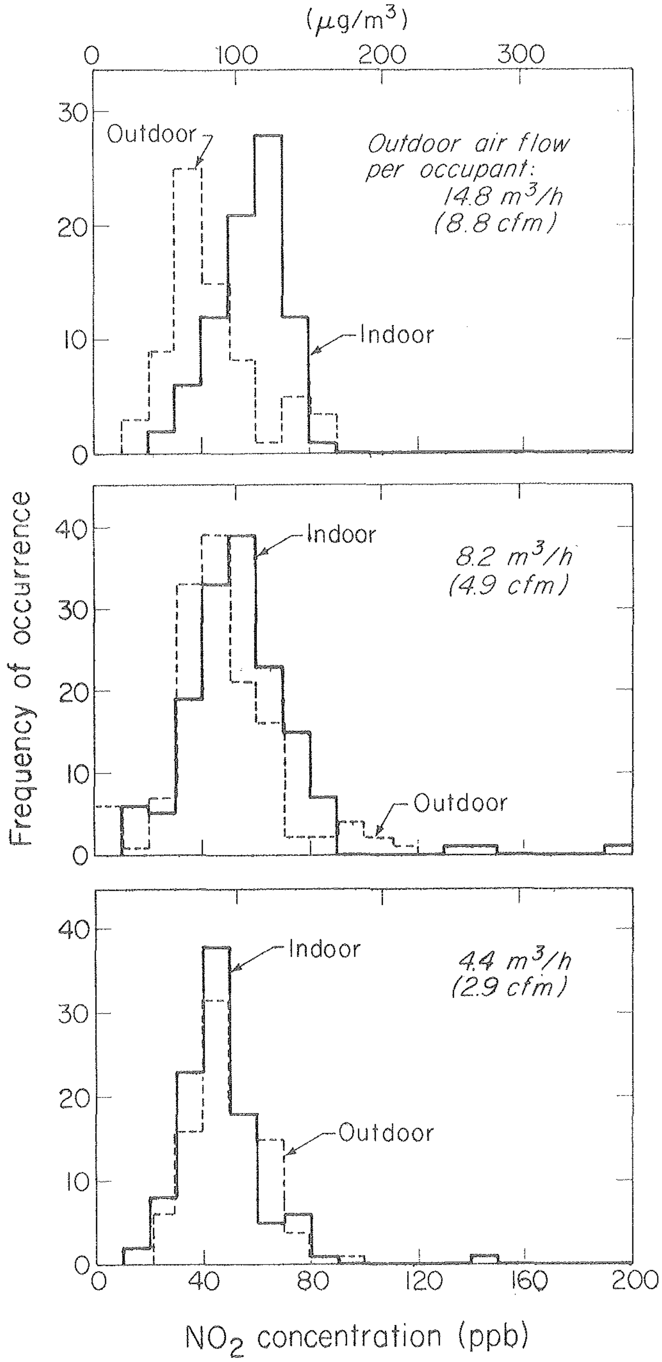
The Appendix contains histograms of the concentrations of the common inorganic pollutants: carbon dioxide, carbon monoxide, nitrogen dioxide, nitric oxide, ozone and sulfur dioxide. Only the data collected during regular school hours, 8:30 A.M. to 3:30 P.M., has been included. For Rooms 323 and 325, the data on a particular pollutant has been grouped by ventilation rate.


CO2 CONCENTRATIONS AT VARIOUS
VENTILATION RATES
Room 323 – Oakland Gardens Elementary School
0
1500
3000
4500
6000
43
30
Outdoor
Outdoor air flow
per occupant:
14.8 m3/h
(8.8 cfm)
Indoor
48
28
8.2 m3/h
(4.9 cfm)
Outdoor
Indoor
49
25
4.4 m3/h
(2.9 cfm)
Outdoor
Indoor
Frequency of occurrence
0
1000
2000
3000
CO2 concentration (ppm)
XBL 808-1573

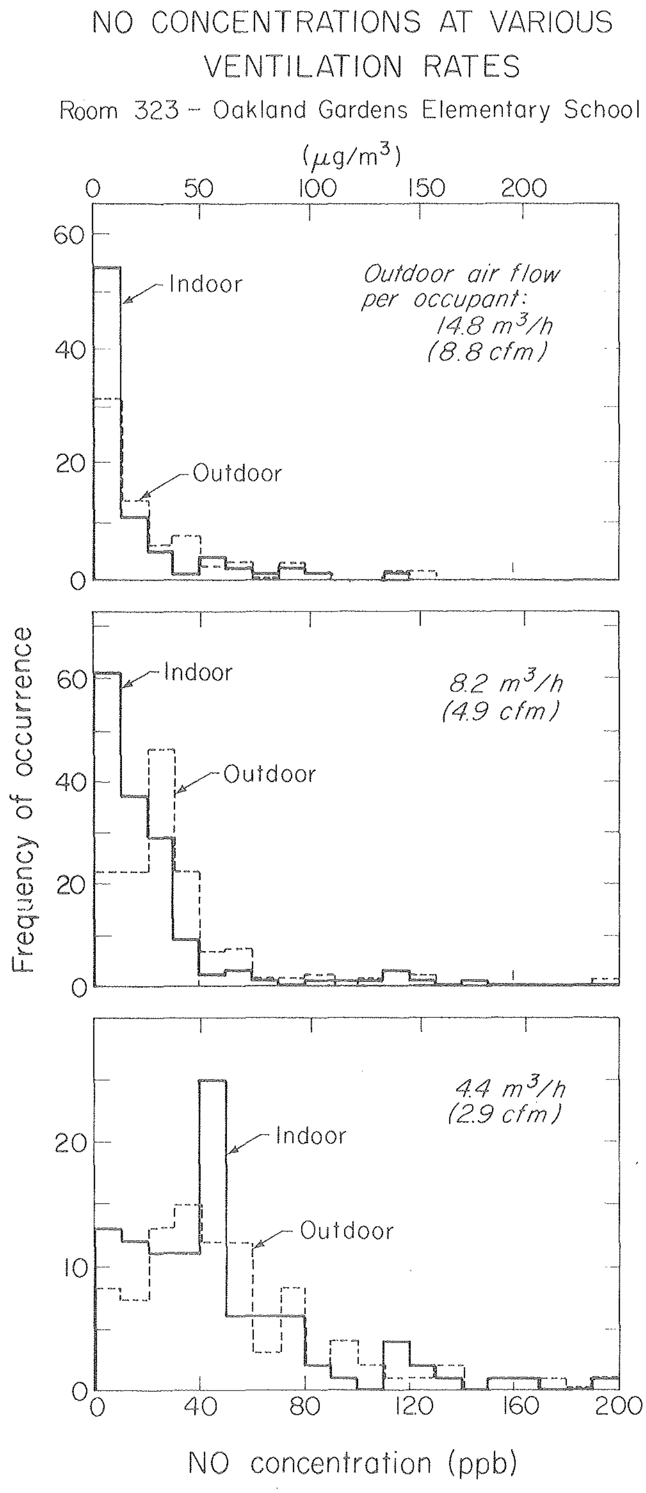

CO CONCENTRATIONS AT VARIOUS VENTILATION RATES
Room 323 - Oakland Gardens Elementary School
(mg/m³)
0
10
20
30
40
50
Indoor
Outdoor air flow per occupant: 14.8 m³/h (8.8 cfm)
Outdoor
8.2 m³/h (4.9 cfm)
4.4 m³/h (2.9 cfm)
Frequency of occurrence
CO concentration (ppm)
XBL 808-1578

NO$_2$ CONCENTRATIONS AT VARIOUS VENTILATION RATES

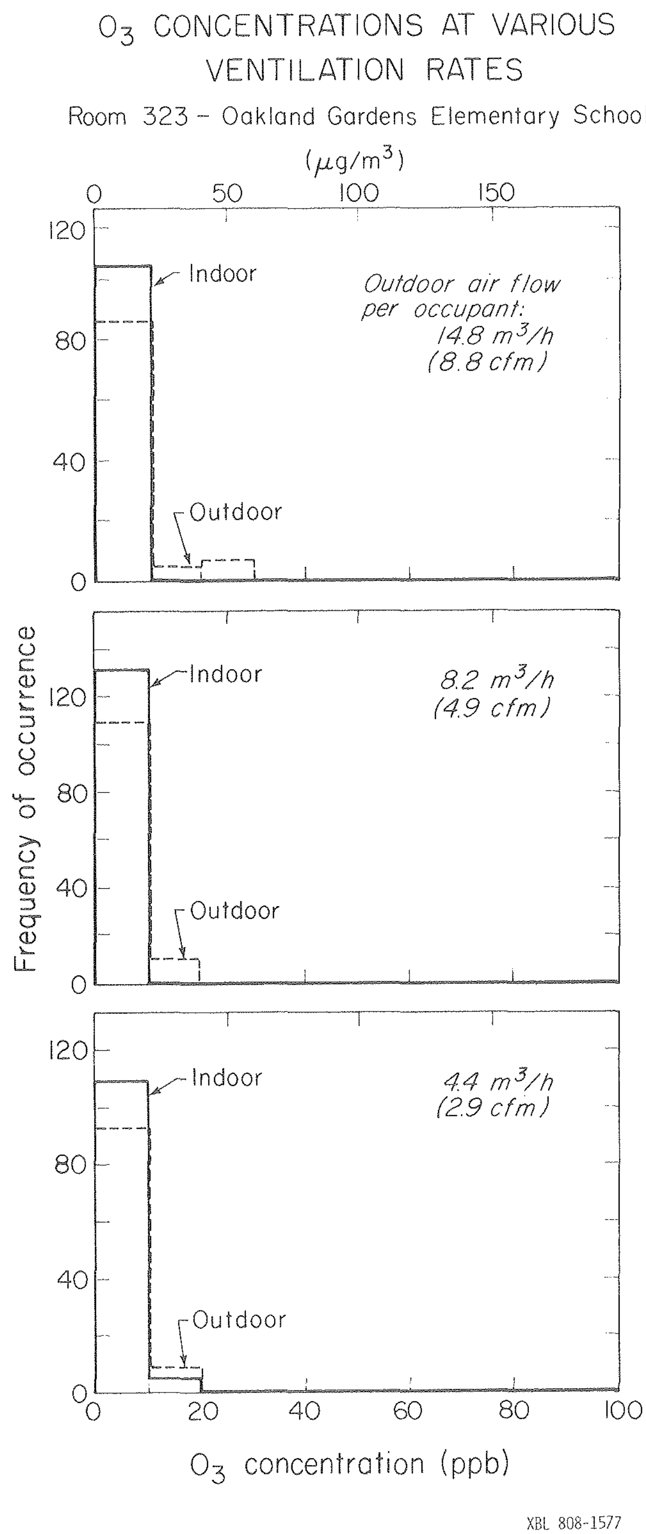
Room 323 – Oakland Gardens Elementary School

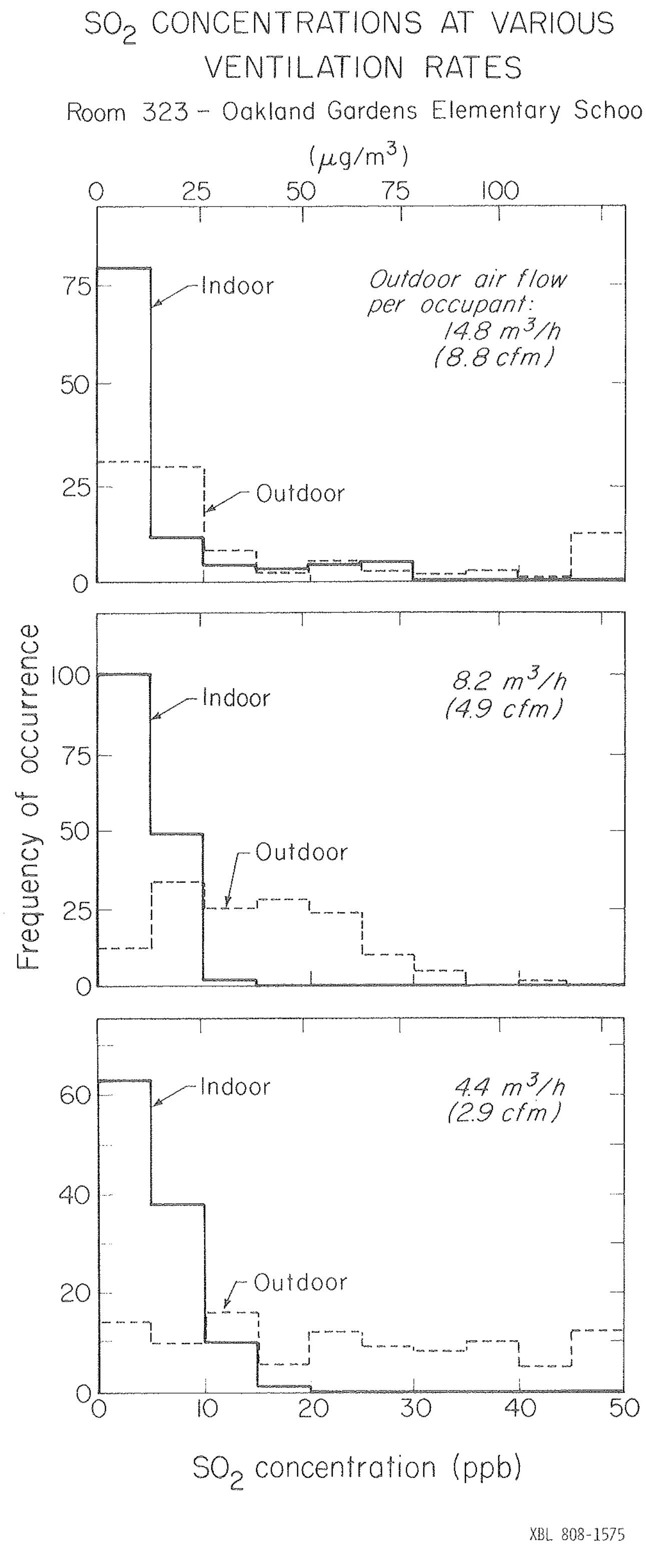


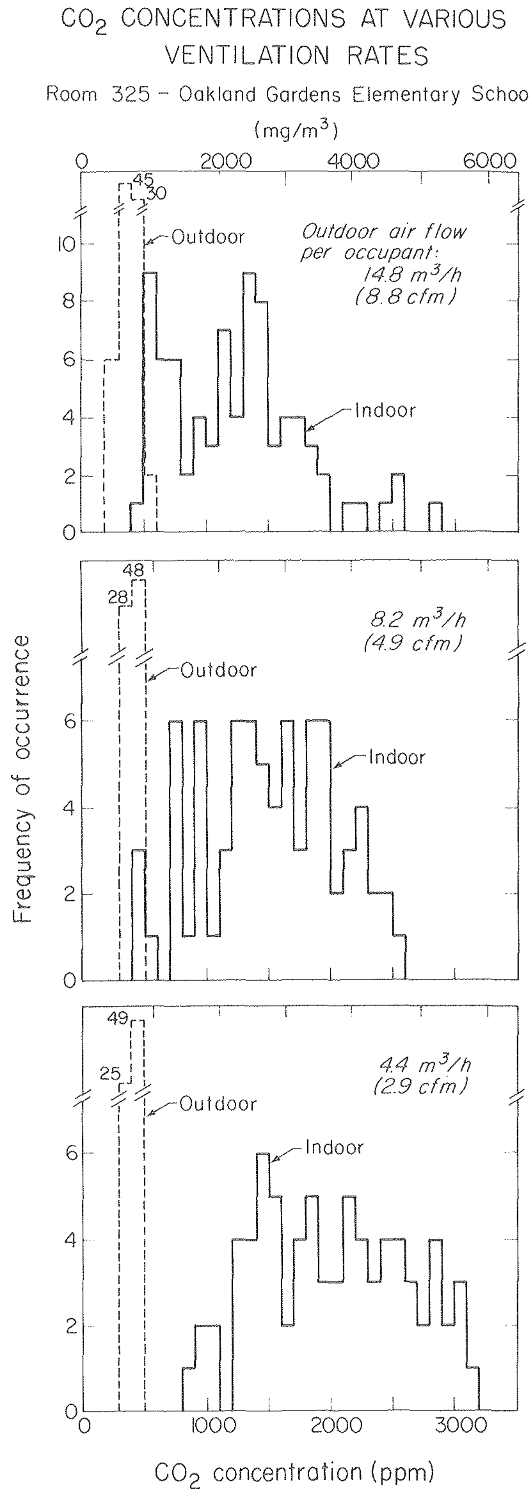

XBL 808-1574


NO CONCENTRATIONS AT VARIOUS
VENTILATION RATES
Room 323 – Oakland Gardens Elementary School
(μg/m³)
0
50
100
150
200
60
40
20
0
Indoor
Outdoor
Outdoor air flow
per occupant:
14.8 m³/h
(8.8 cfm)
Indoor
Outdoor
8.2 m³/h
(4.9 cfm)
Indoor
Outdoor
4.4 m³/h
(2.9 cfm)
20
10
Frequency of occurrence
0
40
80
120
160
200
NO concentration (ppb)

XBL 808-1576


O3 CONCENTRATIONS AT VARIOUS VENTILATION RATES
Room 323 – Oakland Gardens Elementary School
(μg/m3)
0
50
100
150
120
80
40
0
Indoor
Outdoor
Outdoor air flow per occupant: 14.8 m3/h (8.8 cfm)
8.2 m3/h (4.9 cfm)
4.4 m3/h (2.9 cfm)
Frequency of occurrence
0
20
40
60
80
100
O3 concentration (ppb)
XBL 808-1577


SO₂ CONCENTRATIONS AT VARIOUS VENTILATION RATES
Room 323 - Oakland Gardens Elementary School
(μg/m³)
0
25
50
75
100
Indoor
Outdoor
Outdoor air flow per occupant: 14.8 m³/h (8.8 cfm)
8.2 m³/h (4.9 cfm)
4.4 m³/h (2.9 cfm)
Frequency of occurrence
SO₂ concentration (ppb)
0
10
20
30
40
50
60
XBL 808-1575

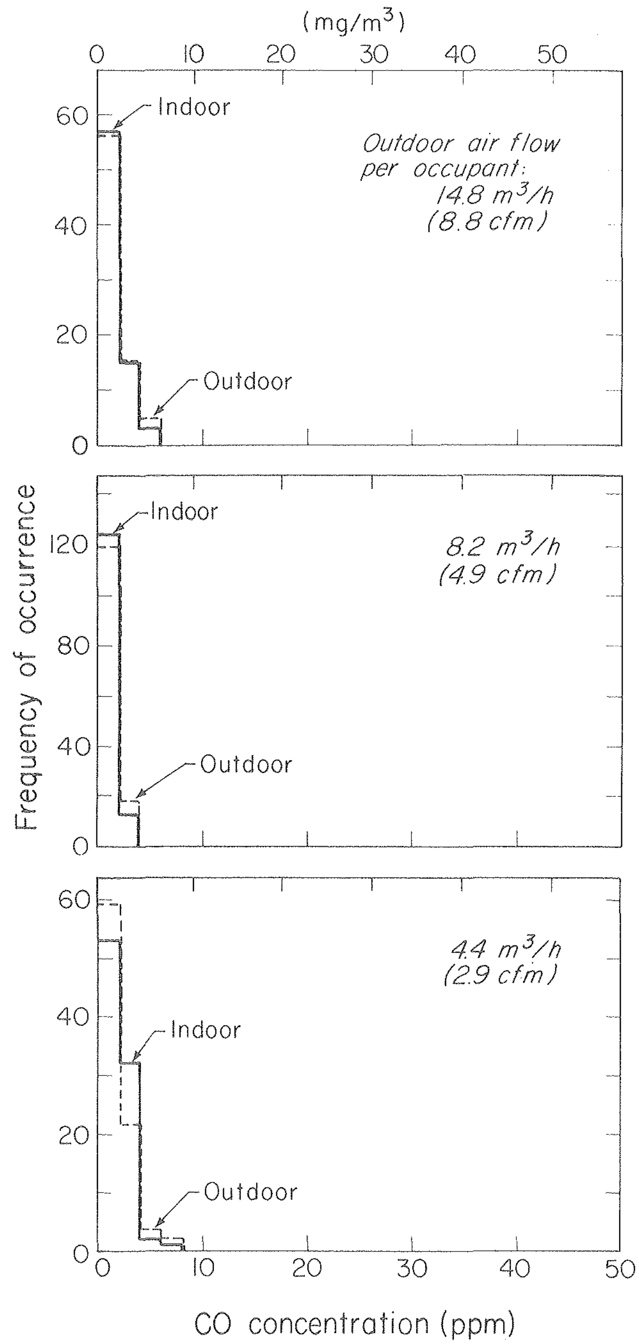


CO2 CONCENTRATIONS AT VARIOUS VENTILATION RATES
Room 325 – Oakland Gardens Elementary School
(mg/m3)
0
2000
4000
6000
45
30
Outdoor
Outdoor air flow per occupant:
14.8 m3/h
(8.8 cfm)
Indoor
48
28
8.2 m3/h
(4.9 cfm)
Outdoor
Indoor
49
25
4.4 m3/h
(2.9 cfm)
Outdoor
Indoor
Frequency of occurrence
0
1000
2000
3000
CO2 concentration (ppm)


XBL 808-1570

CO CONCENTRATIONS AT VARIOUS VENTILATION RATES

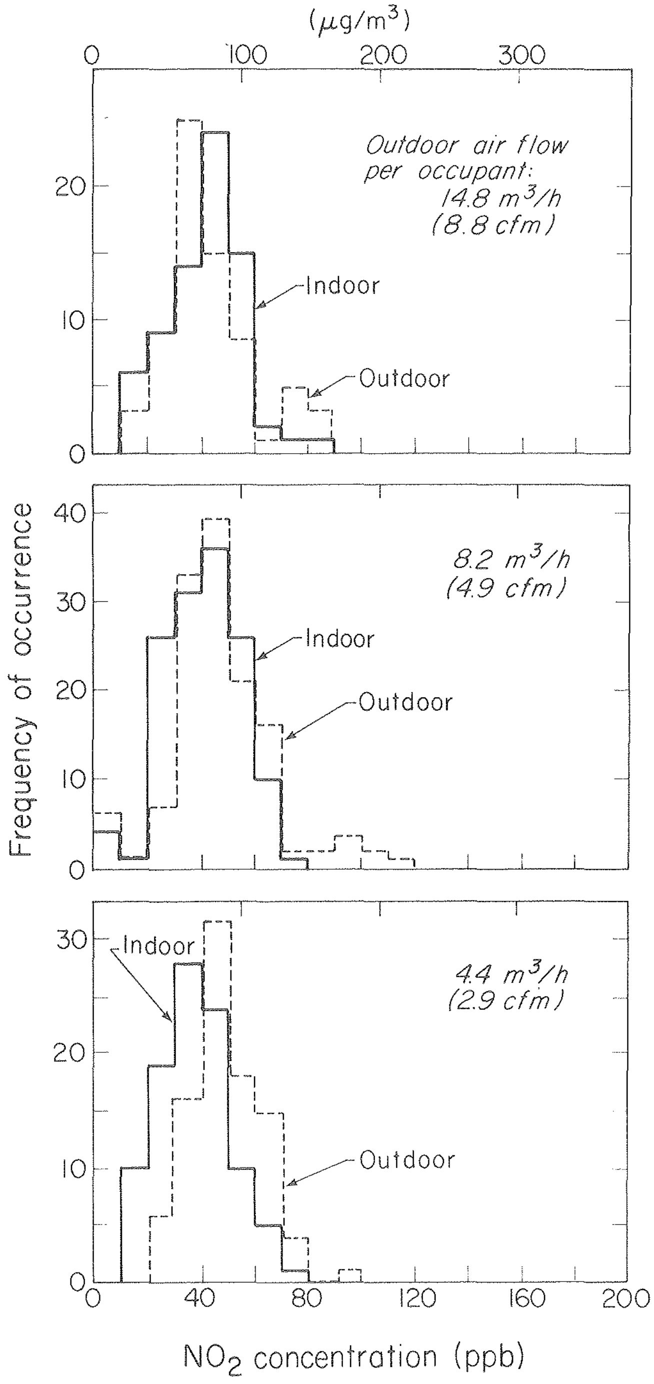
Room 325 - Oakland Gardens Elementary School




XBL 808-1566

# $NO_2$ CONCENTRATIONS AT VARIOUS VENTILATION RATES

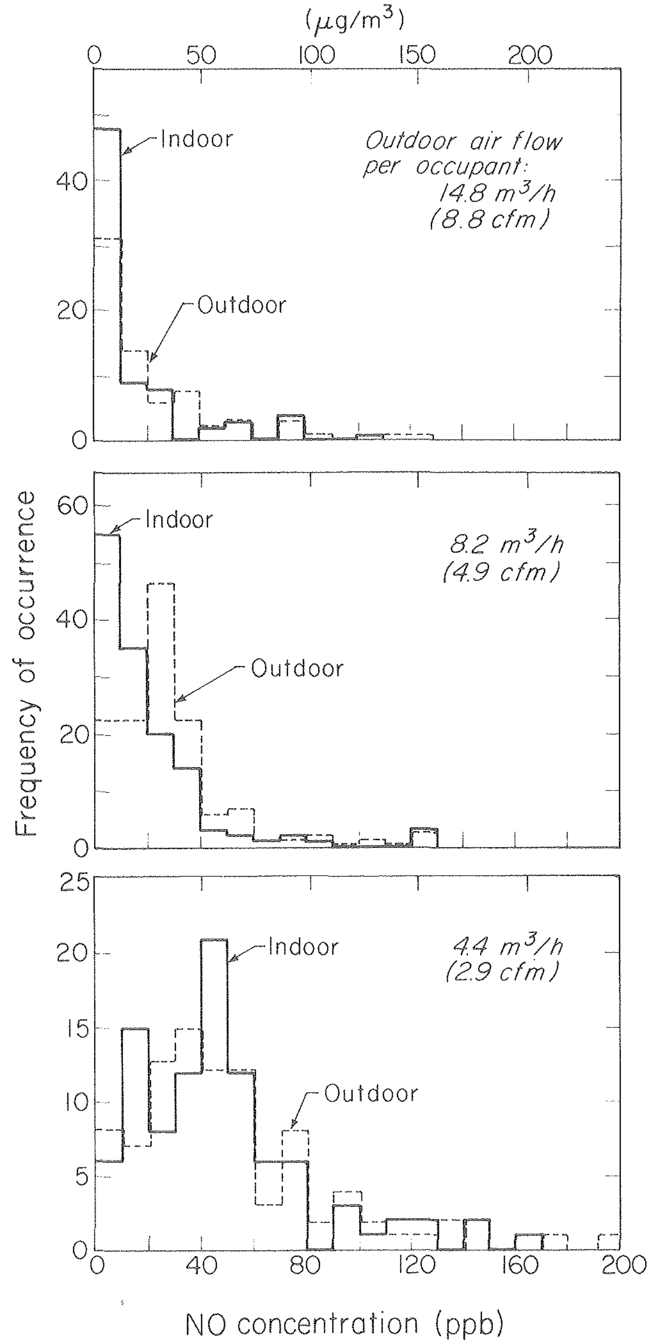
Room 325 - Oakland Gardens Elementary School




XBL 808-1581

NO CONCENTRATIONS AT VARIOUS VENTILATION RATES

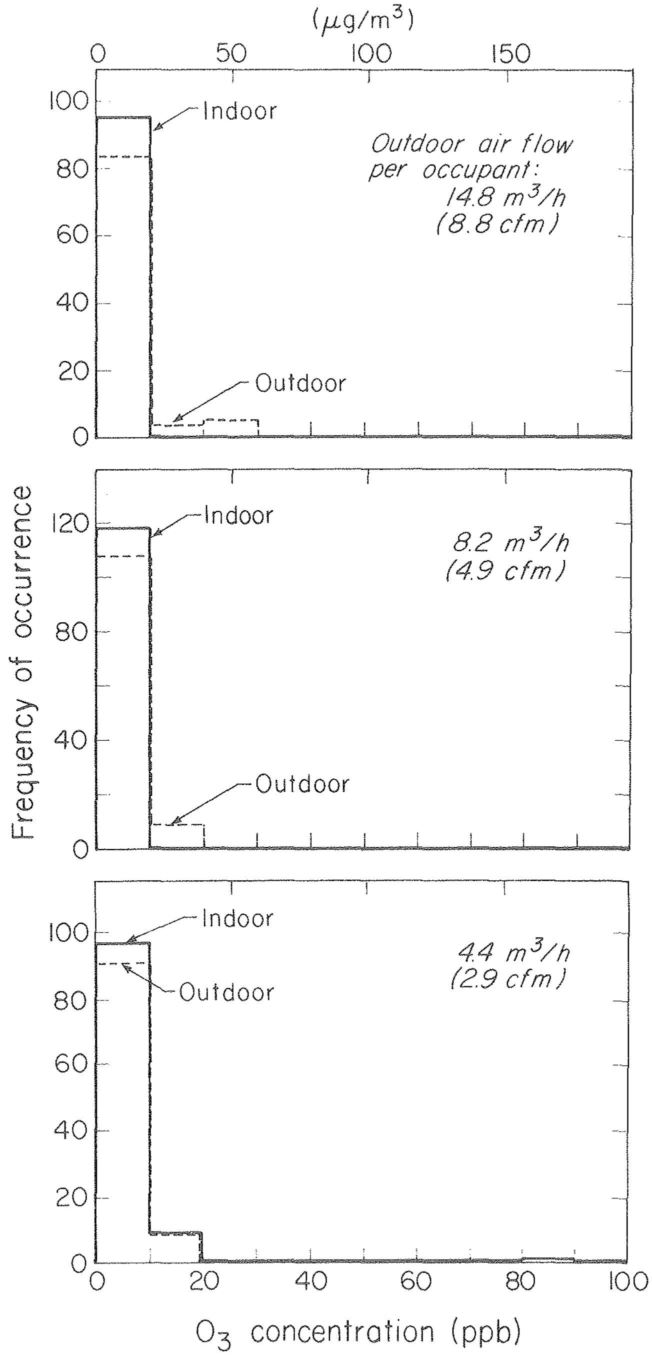
Room 325 – Oakland Gardens Elementary School



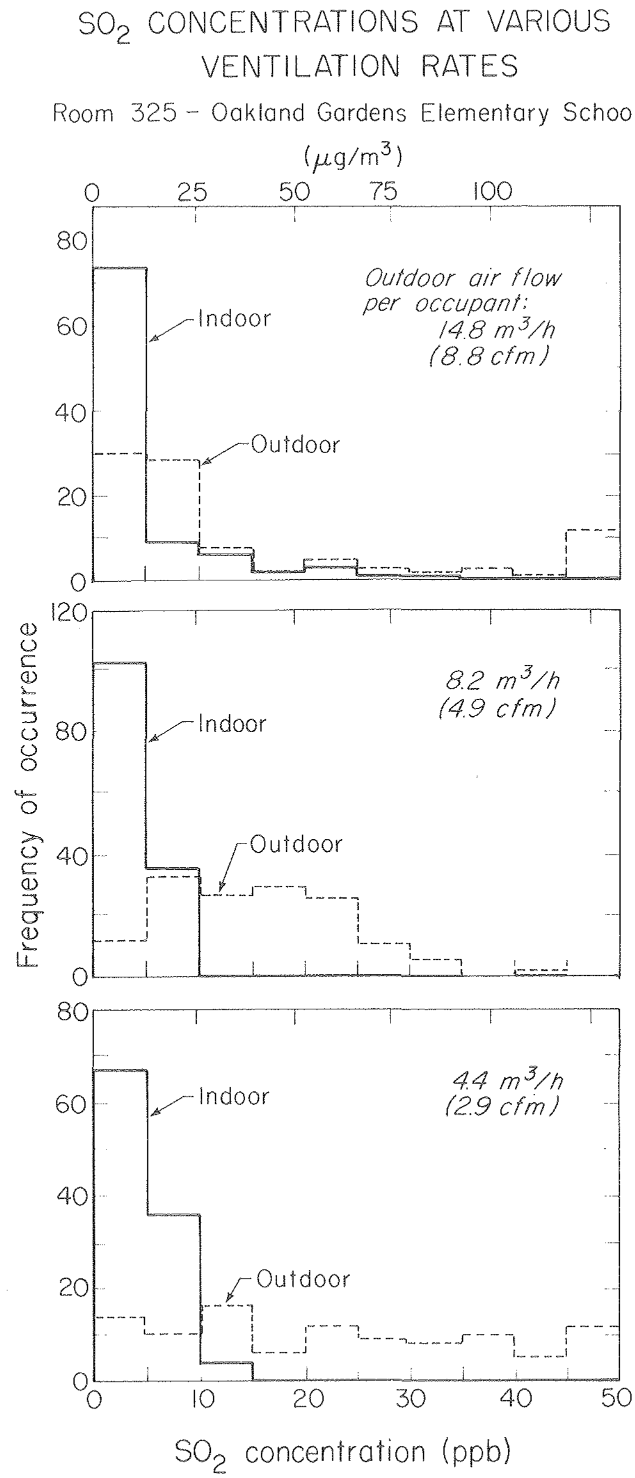

XBL 808-1569

$O_3$ CONCENTRATIONS AT VARIOUS VENTILATION RATES

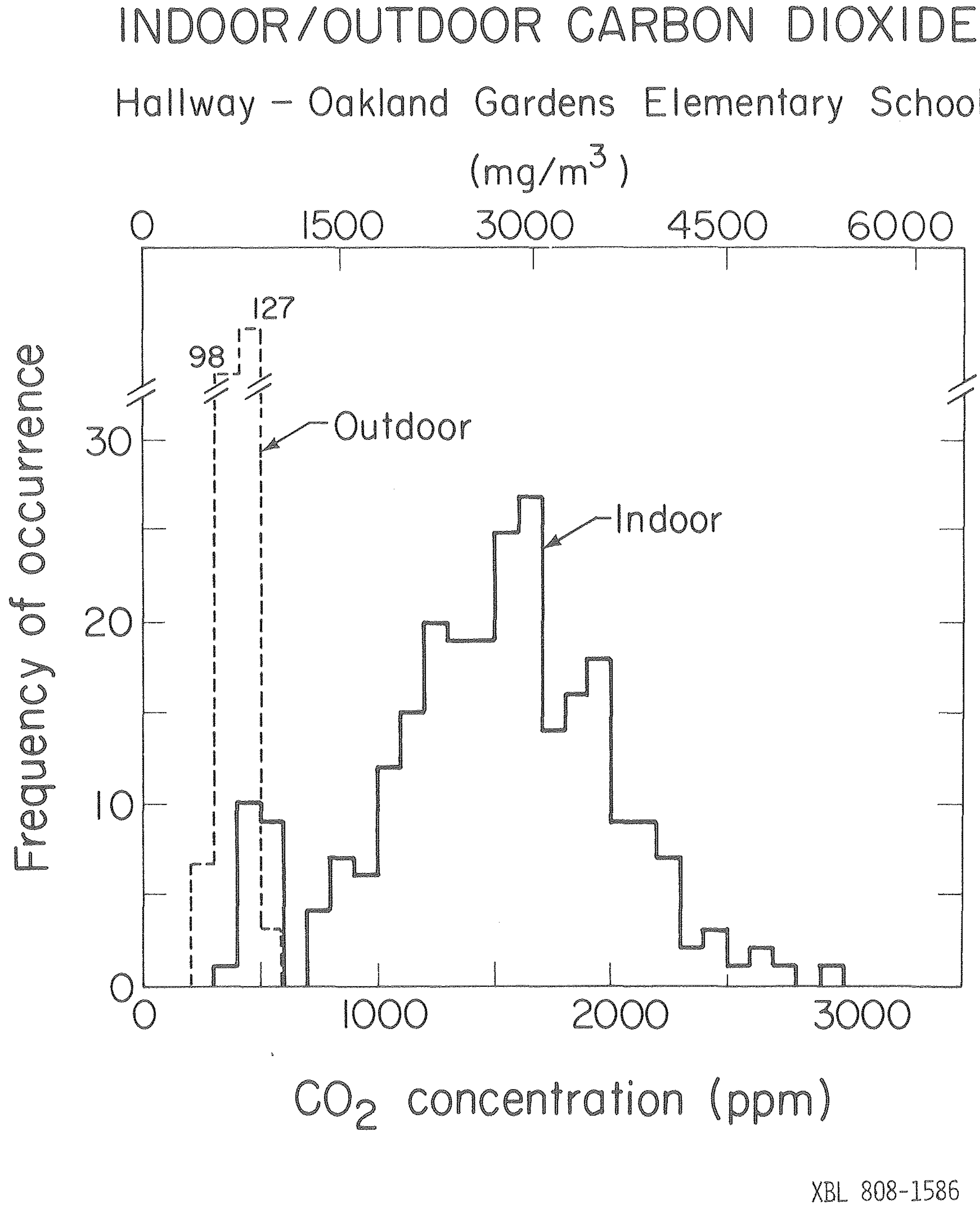
Room 325 - Oakland Gardens Elementary School



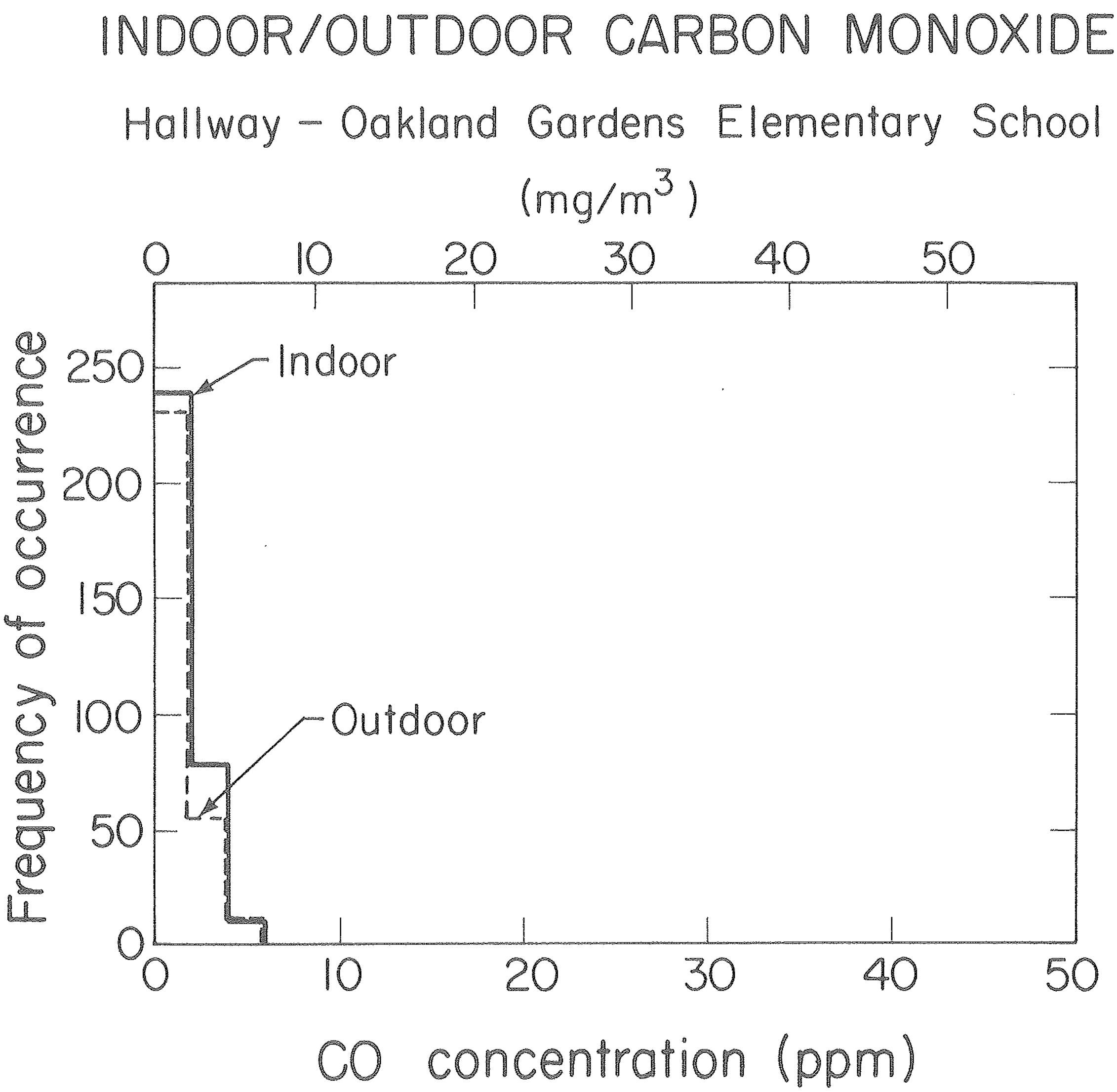

XBL 808-1580


SO2 CONCENTRATIONS AT VARIOUS VENTILATION RATES
Room 325 – Oakland Gardens Elementary School
(μg/m3)
0
25
50
75
100
Outdoor air flow per occupant: 14.8 m3/h (8.8 cfm)
Indoor
Outdoor
8.2 m3/h (4.9 cfm)
4.4 m3/h (2.9 cfm)
Frequency of occurrence
0
10
20
30
40
50
SO2 concentration (ppb)

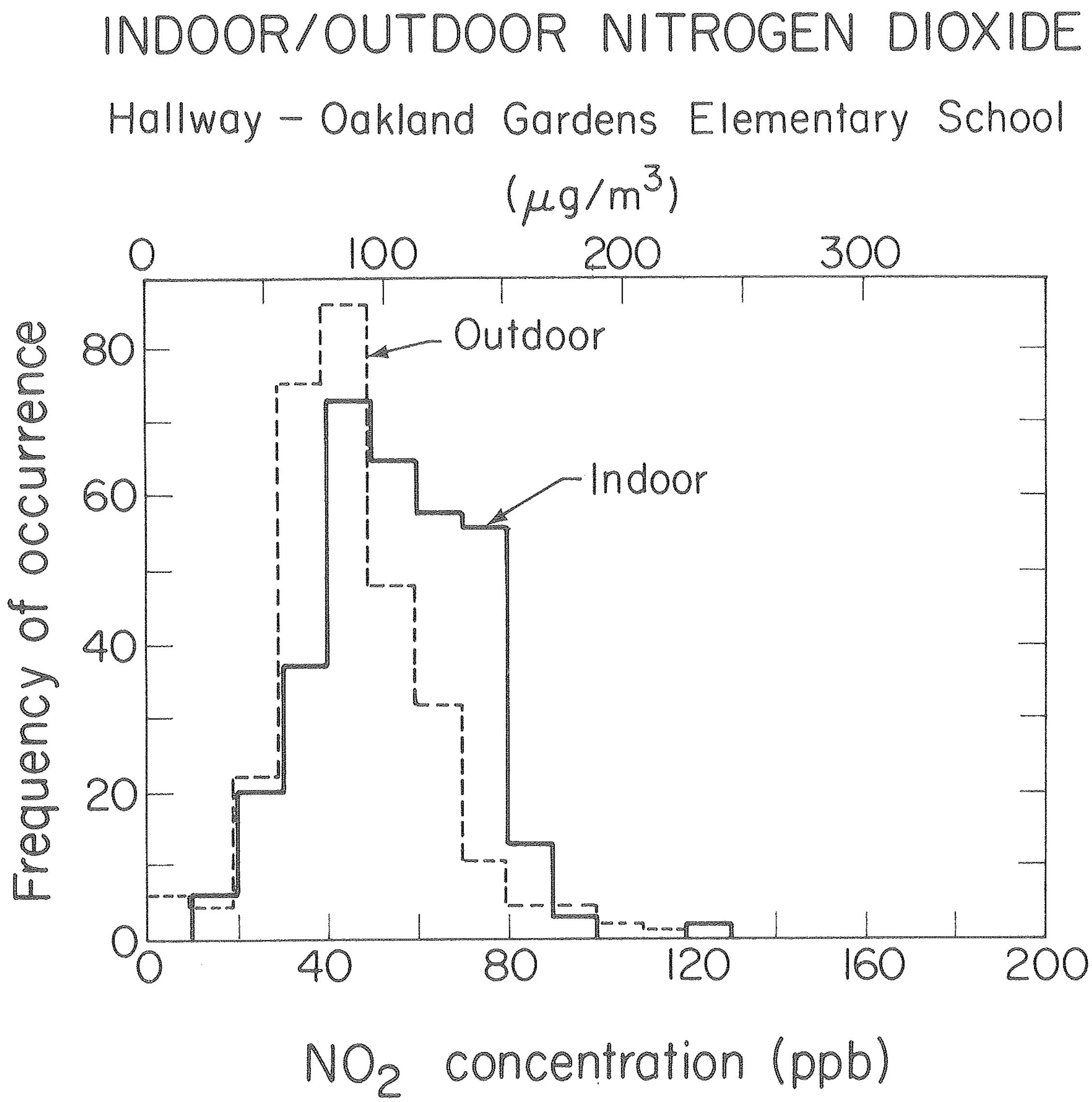
XBL 808-1579


INDOOR/OUTDOOR CARBON DIOXIDE
Hallway – Oakland Gardens Elementary School
(mg/m3)
0
1500
3000
4500
6000
127
98
Outdoor
Indoor
Frequency of occurrence
30
20
10
0
0
1000
2000
3000
CO2 concentration (ppm)

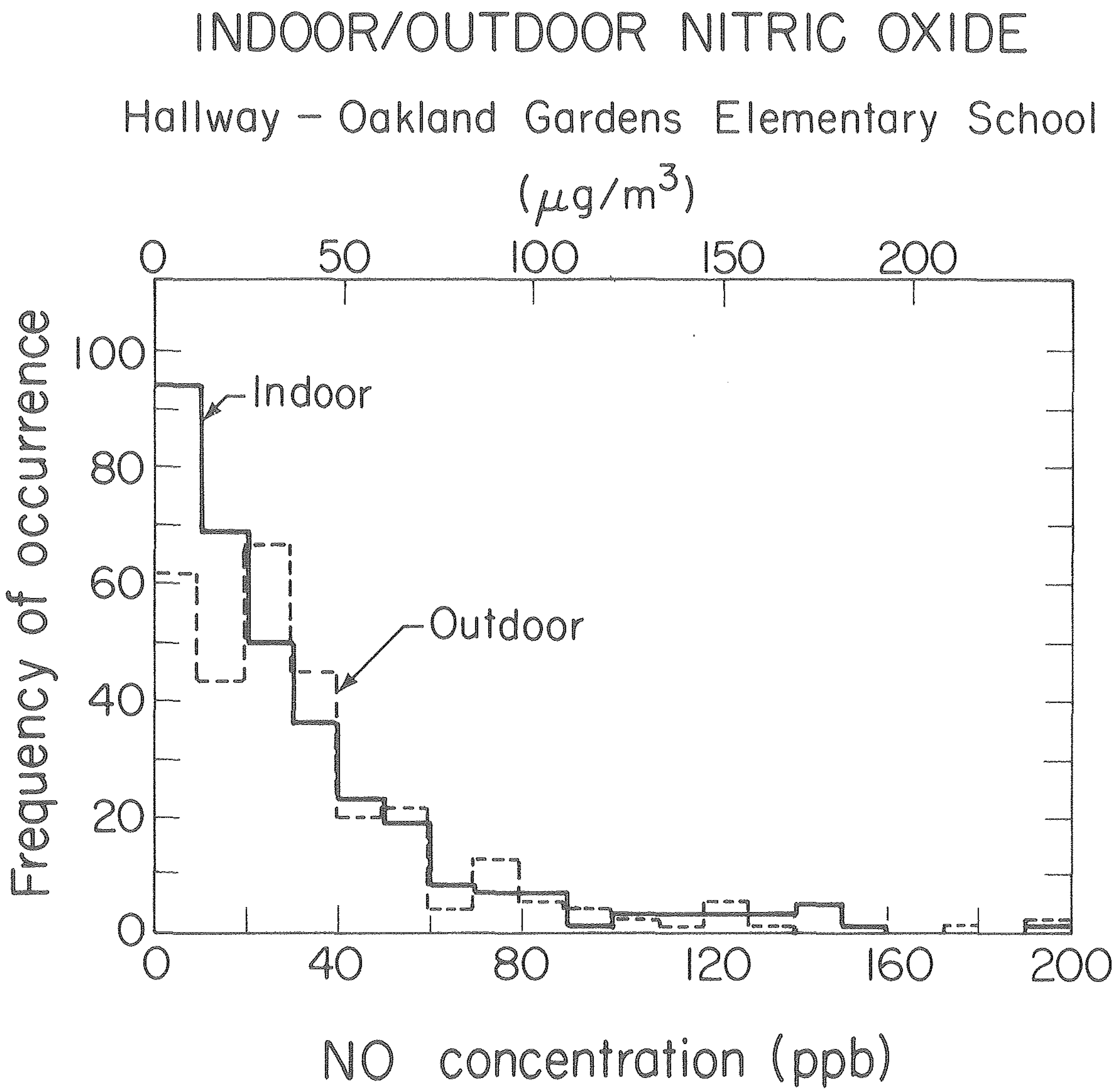
XBL 808-1586


INDOOR/OUTDOOR CARBON MONOXIDE
Hallway – Oakland Gardens Elementary School
(mg/m3)
0
10
20
30
40
50
Indoor
Outdoor
Frequency of occurrence
250
200
150
100
50
0
0
10
20
30
40
50
CO concentration (ppm)

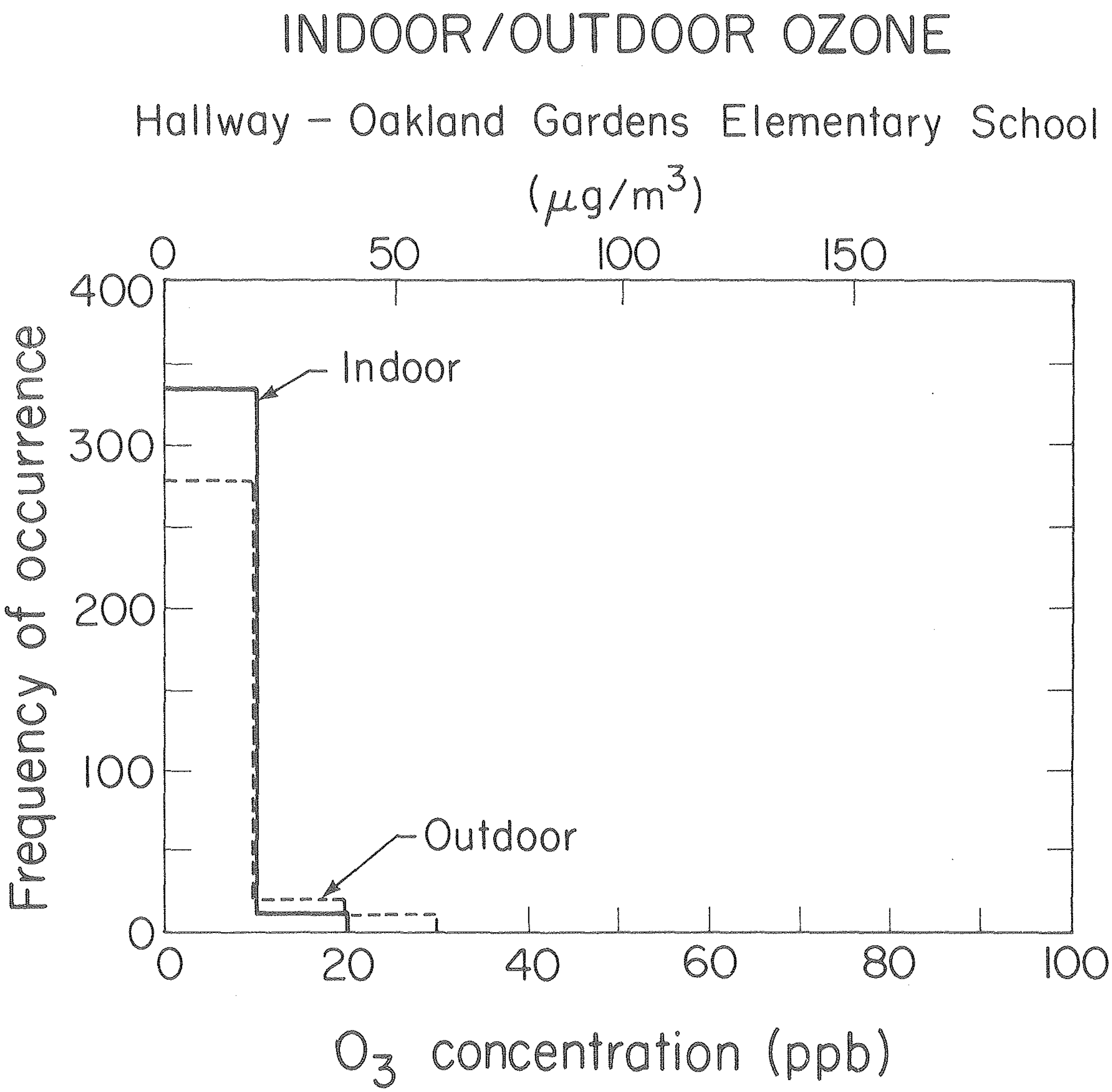
XBL 808-1587


INDOOR/OUTDOOR NITROGEN DIOXIDE
Hallway – Oakland Gardens Elementary School
(μg/m3)
0
100
200
300
Outdoor
Indoor
Frequency of occurrence
80
60
40
20
0
0
40
80
120
160
200
NO2 concentration (ppb)

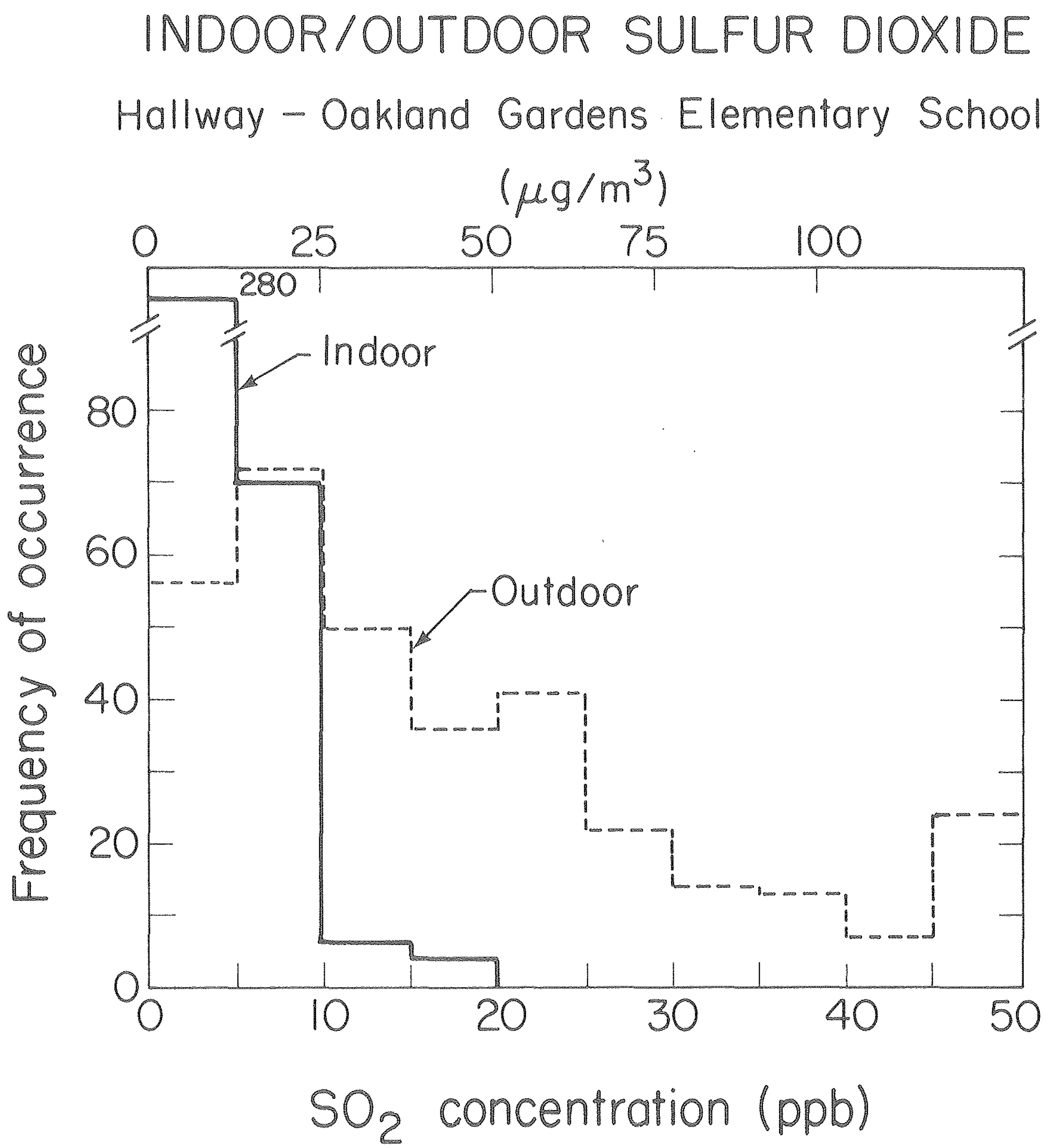
XBL 808-1585


INDOOR/OUTDOOR NITRIC OXIDE
Hallway – Oakland Gardens Elementary School
(μg/m³)
0
50
100
150
200
100
80
60
40
20
0
Frequency of occurrence
Indoor
Outdoor
0
40
80
120
160
200
NO concentration (ppb)

XBL 808-1583


INDOOR/OUTDOOR OZONE
Hallway – Oakland Gardens Elementary School
(μg/m3)
0
50
100
150
400
300
200
100
0
Indoor
Outdoor
0
20
40
60
80
100
Frequency of occurrence
O3 concentration (ppb)

XBL 808-1588


INDOOR/OUTDOOR SULFUR DIOXIDE
Hallway – Oakland Gardens Elementary School
(μg/m³)
0
25
50
75
100
280
Indoor
Outdoor
Frequency of occurrence
80
60
40
20
0
0
10
20
30
40
50
SO₂ concentration (ppb)

XBL 808-1584