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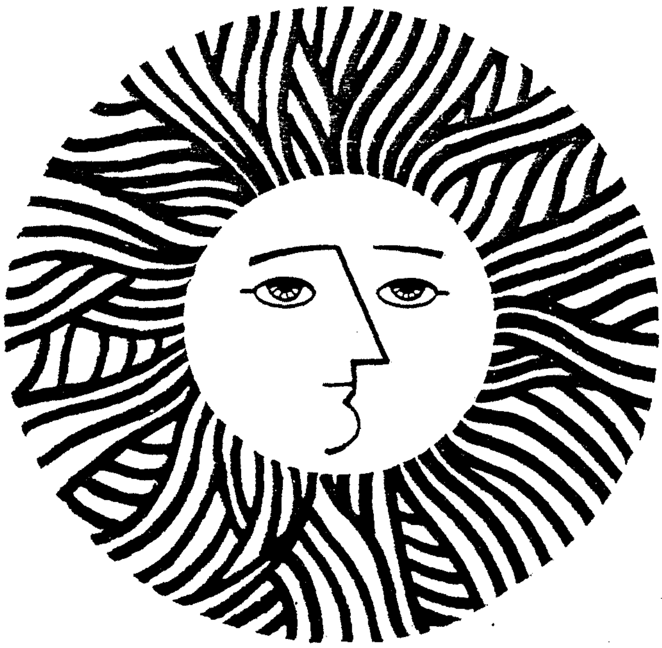

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THE EFFECT OF REDUCED VENTILATION ON INDOOR AIR QUALITY AND ENERGY USE IN SCHOOLS

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ABSTRACT

The indoor air quality in an air conditioned California high school has been measured over a variety of ventilation rates ranging from 13.3 cubic feet of outside air per minute for each classroom occupant to approximately 1.5 cfm per occupant. The purpose of this pilot study was to determine the effect of reduced ventilation on indoor air quality and energy use.

Parameters measured include outside air supply rate, the occupants' subjective perception of indoor air quality, airborne microbes, carbon dioxide, carbon monoxide, nitrogen oxides, sulfur dioxide, and ozone in two classrooms, a hall, and outdoors. Carbon dioxide was the only parameter to show a substantial increase in indoor concentration when the ventilation rate was reduced; however, classroom levels still remained far below levels considered to be a health hazard. This study indicates that moderate energy savings are possible at Carondelet High School without significant deterioration of indoor air quality, and that substantial energy savings would be possible in a more severe climatic region.

keywords: air pollution, buildings, carbon dioxide
energy conservation, indoor air quality, schools, ventilation

INTRODUCTION

A series of field studies in educational facilities and hospitals have been undertaken to investigate energy savings achieved by reducing ventilation. A significant part of the work is directed toward assessing the impact such reductions might have on the health and comfort of building occupants. In order to measure the effects of changes in ventilation rates on indoor air quality and energy utilization in buildings, a mobile laboratory was designed and fabricated. This report discusses the results of the first indoor air quality field monitoring study. Measurements in this pilot study were conducted at Carondelet High School in Concord, California.

In schools, the main areas of concern, with respect to ventilation requirements, are control of odors and airborne microbes. Chemical contaminants have received less attention thus far. Measurements at Carondelet High School included all of the major parameters of concern.

1e EEB Mobile Laboratory [1] was positioned outside Carondelet High School. Air rom four locations within the structure was drawn through teflon sampling lines nto the trailer for analysis. By sequentially sampling the lines (one of which as used to monitor incoming outdoor ambient air), the outdoor air quality was onitored where it entered the building and the indoor air quality was monitored 1 two classrooms and the hallway (near the return air register). The individual ampling sites were each monitored for ten-minute intervals every forty minutes.

arondelet High School is a two-story, air conditioned building with about 40 lassrooms and 700 occupants. The heating, ventilation, and air conditioning HVAC) system is a combination air-water system with room induction units. Classooms are supplied with primary air, which is a mixture of outside and recircuated air. There is one supply fan for primary air, and distribution ductwork nroughout the building to the terminal induction units located in each room. ach induction unit has a hot water reheat coil.

ne outside air entering the school was measured and regulated at various flow ate in order to assess the energy savings and the impact on indoor air quality. ne air quality was monitored under three ventilation rates. The first rate was ne normal operating mode with the roof dampers in the fully open position. The econd and third rates restricted total outdoor air to the school. The amounts of utdoor air supplied to the entire school in the three cases were: 20,000 cfm, 700 cfm, and 2300 cfm, respectively. It should be noted that a decision to restrict the outdoor air to 2300 cfm was not made until it had been established that ne indoor air quality at 3700 cfm was still very good. In a typical classroom ith 27 students receiving 800 cfm primary air, these rates correspond to 13.3, .5, and 1.5 cfm of outside air per occupant (in S.I. units, 22.6, 4.2, and 2.5 ^{3}/h respectively).

ata were collected for ventilation rates of 20,000 cfm, 3700 cfm, and 2300 cfm, nich represent the volume of outside air supplied to the entire building each inute. It should be noted that data were collected for only a few days for each ate, and that classroom attendance was slightly irregular, since the monitoring ook place during the last few weeks of the school year.

RESULTS AND DISCUSSION

Ventilation Rate and Sensory Perception of Indoor Air Quality

n order to assess the potential reaction of the students to the changes in ventiation rates, a questionnaire on the quality of the indoor environment was disributed to the classroom occupants. The questionnaires were filled out every ther day at 11:15 a.m. This type of questionnaire which uses bipolar adjectives s environmental descriptors, has been used in other studies to measure fashion references, food tastes and architectural tastes [2]. The students' subjective udgment of odor level at various ventilation rates was of particular interest, ince odor control is probably the basis for current ventilation requirements in chools.

Results of this survey showed no deterioration of student comfort caused by lecreased ventilation rates. The results from one classroom are shown in Figure . Similar results were also obtained in the second classroom. The subjective rating ranged from 1 to 9 with lower numbers corresponding to the first adjective n parentheses. For example, the high odor intensity numbers would indicate strong odor perception, whereas low numbers would indicate little or no odor per-

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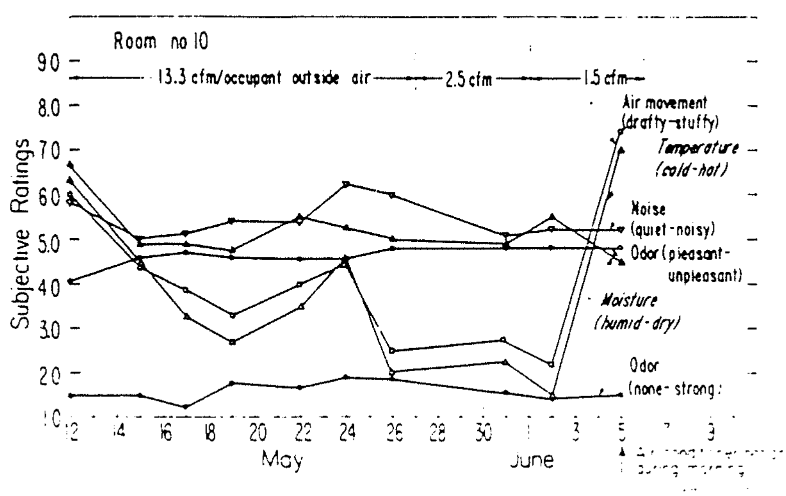

Fig. 1 Subjective perceptions of six components of indoor air quality are shown as a function of day of month and outside air ventilation rate for a classroom.

ception. As can be seen in the figure occupant perception of odor intensity essentially remained constant and weak 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 and was independent of the ventilation rate. Perceived and measured indoor temperatures were strongly correlated.

Ventilation Rate and Microbial Burden

The bacterial content of the air was measured by modified Andersen samplers fabricated and operated by the Naval Biosciences Laboratory [3]. 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, allowing the colonies to be counted. 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 I. There is an increase in the number of CFP/m^3 and in the number median diameter (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. However, only the rise in NMD appears to be statistically significant.

It is not known why the number of airborne CFP is consistently higher in Room 11 than in Room 10. 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

*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.

source of CFP in the outside air. In any case, decreasing the outside air ventilation rate did not increase the microbial burden in the classrooms.

Table I Summary of Data on Airborne Colony Forming Particles Collected at Carondelet High School (based on 114 samples).

Outside Air Ventilation Rate (cfm/person)	Room 11 (CFP/m^3)		Room 10 (CFP/m^3)	
	Occupied	Unoccupied†	Occupied	Unoccupied†
13.3	160(5.4)	54(4.3)	107(5.4)	27(2.4)
2.0*	115(6.6)	47(3.5)	75(5.8)	37(2.8)

† = 7:00 a.m. sample; ventilation turned on at 6:30 a.m.
( ) = The Number Median Diameter (NMD) in μm.
* = Data combined at 1.5 cfm and 2.5 cfm per person outside air ventilation rate.

Ventilation Rates and Chemical Indoor Air Quality

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.

Because the air quality in the two classrooms and hall was found to be nearly identical, the following discussion refers to only one indoor site; however, the conclusions are intended to apply to the entire school.

Figure 2 shows three histograms of the frequency of occurrence of CO_2 concentration in one classroom and outdoors for all data points between 8:00 a.m. and 3:00 p.m. These diagrams show the ranges of concentrations observed for each ventilation rate and how these ranges shifted as the ventilation rates were reduced. 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 occupational standards of 5000 to 10,000 ppm [4-6]. These concentrations refer to a time weighted average concentration for up to 8 and 10-hour workshifts in a 40-hour work week. Studies have shown that humans may be repeatedly exposed to these concentrations day after day without adverse health effects [7].

The ratio of indoor concentration to outdoor concentration for CO_2 was calculated for all data points between 8:00 a.m. and 3:00 p.m. for each ventilation rate. Although limited data were available at the most restricted ventilation rates, these ratios increased as the ventilation rates were reduced.

Figure 3 shows the frequency distribution of indoor/outdoor ozone ratios as ventilation rates were reduced. Ozone concentrations were generally lower when the flow of outdoor air into the school was reduced. This behavior is characteristic of reactive pollutants when the primary sources are outdoors and the building surfaces function as chemical sinks. This component of indoor air quality improved at reduced ventilation rates.

For CO, the indoor and outdoor concentrations were nearly equal at all ventilation rates. Significant indoor sources of carbon monoxide (such as cigarette smoke) were not expected at this school.

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Because this was the first field site for the EEB Mobile Laboratory, some equipment problems were experienced and data are not complete for all parameters. Sulfur dioxide results are not given because of electronic drift problems but indoor

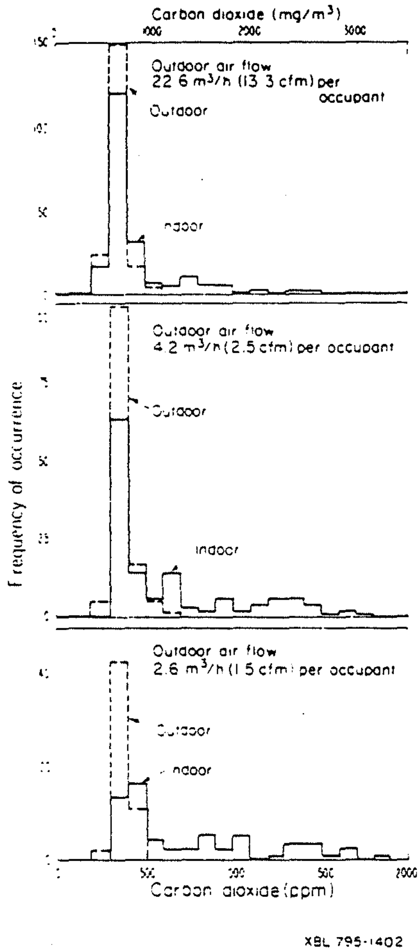

Fig. 2 Histograms showing frequency distributions of CO_2 concentrations measured at three ventilation rates. Data points, obtained from 10-minute sampling intervals, have been sorted into bins along the x-axis. Each bin width is 100 ppm. Data represents school days only, but includes measurements for 24 hours each day. Ambient CO_2 concentrations are typically 300-500 ppm.

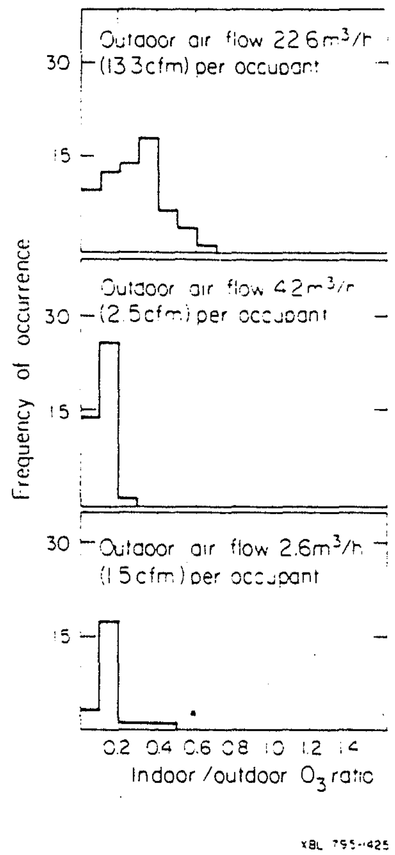

Fig. 3 Histograms showing the frequency distributions of indoor/outdoor O_3 ratios at three ventilation rates. Data points were obtained from 10-minute sampling intervals. Ratios were calculated only for data collected between 8 a.m. and 3 p.m. The ratios were sorted into bins along the x-axis. The width of each bin is 0.1 units.

concentrations tended to be lower than outdoor ones and no concentrations higher than 30 ppb were measured. Concentrations of the nitrogen oxides were measured only during the early part of the study and found to be less than 70 ppb and comparable at all locations. However, because of the small amount of quantitative data, the results of monitoring these parameters are not illustrated.

Energy Savings

Total energy use (including space heating and cooling, water heating and lighting) for Carondelet High School costs $41,000 per year at 1978 prices for natural gas and electricity. This yearly energy cost is the energy cost for two separate buildings (one combined utility bill for both buildings), one housing the 40 classrooms (56,000 ft^2) and the other consisting of a gymnasium plus art rooms (16,000 ft^2). The utility bill is divided into two parts: electrical energy mostly for space cooling and lighting ($30,000), and natural gas for water and space heating ($11,000). Ventilation rate changes were made only in the main building which we estimate as having utility bills of $31,000 per year, assuming the energy use to be proportional to floor area.

Data obtained by LBL at At Carondelet High School and at a Columbus, Ohio school [7] and by other experimenters [8] suggest that a 10 cfm per person reduction in the outside air ventilation rate is readily achievable. The data also indicates that 2.5 cfm per person of outside air is sufficient to maintain CO_2 levels below 5000 ppm and odor intensity below the annoyance threshold for classroom occupants.

Table II is a compilation of yearly ventilation heating loads [9] for selected cities in the United States. For most cities in the table, the degree days can be used to obtain an approximate value of the ventilation heating load for the 9:00 a.m. to 5:00 p.m. period. The greatest energy savings for schools will occur in the Northeast and North Central regions of the United States. Cooling loads have not been calculated here, but for buildings operating year-round, considerable energy and peak power savings can also be expected during the summer in most regions of the United States. As can be seen from Table II, the yearly energy savings from outside air reduction in colder climates will be more than double the savings at Concord, California (Concord has a daytime winter climate similar to that of San Francisco).

Table II Yearly Ventilation Heating Load for Selected Cities

City	Degree Days (base 65°F)	Heating Load $\left(\frac{Btu}{cfm}\right)$
Albany, New York	6874	58,652
Pittsburgh, Pennsylvania	5987	52,756
Chicago, Illinois	6154	56,790
Minneapolis, Minnesota	8383	69,319
San Francisco, California	3015	24,244
Los Angeles, California	2061	11,778
Jacksonville, Florida	1238	9,028

The energy cost savings during the heating season for the main building have been computed to be $1,340 [9]. Therefore, in the main classroom building, almost 16% of the cost of natural gas (used for space and water heating) can be saved by a 17,000 cfm ventilation rate reduction. Energy cost savings for the cooling season are estimated to be $275, plus peak power charges.

Therefore, the total energy savings realized by reducing the outside air ventilation rate by 17,000 cfm is more than $1,600 or 5.2% of the total energy cost for the main classroom building. However, this estimate may be low since the gym probably has higher energy use per square foot than the main building due to the need for more outside air (for odor control) and more hot water. It is important to note that in a mild climate such as in Concord, California, space heating and cooling together account for only a relatively small fraction (approximately 33%) of total energy cost thereby limiting the potential energy cost savings by ventilation rate reduction. In the Northeast and North Central parts of the U.S. space heating and cooling together account for 60% and 50%, respectively, of total energy use; therefore, in such locations, it should be possible to achieve energy savings of about 10% of the total energy use by the ventilation reduction described above.

Further energy savings can be effected by controlling outside ventilation air according to actual occupancy of classrooms, gymnasiums, cafeterias, etc. LBL is undertaking an investigation of variable ventilation control systems based on air quality detection for educational facilities [9].

CONCLUSIONS

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 (such as 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.

Based upon field monitoring results at Carondelet and Fairmoor School, it appears that in classrooms, the outside air ventilation rate can be safely reduced to the ASHRAE minimum of 5 cfm/occupant and probably significantly lower. Since the amount of outside air entering the school could be decreased without any adverse effect on the health, safety, or comfort of the occupants, moderate energy savings could be achieved by lowering the fresh air ventilation rates at the Concord, California, school. However, in more severe climates, the energy savings achieved by a reduction in outside air ventilation rates should be much higher.

The field monitoring activities at Carondelet High School represent a pilot study. As the results from future studies are ascertained, we expect to establish the relationship between outside air ventilation rates and indoor air quality in schools, hospitals and residential buildings.

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