BUILDING RESEARCH NOTE

CARBON DIOXIDE MEASUREMENT IN OPEN-CLASSROOM SCHOOL

WITH OUTSIDE AIR-SUPPLY DAMPER CLOSED

TO CONSERVE ENERGY

by

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Ottawa, October 1980

National Research Council Canada   Conseil national de recherches Canada

NO 169

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ABSTRACT

Carbon dioxide concentrations in the classrooms of a small elementary school were measured one week in February 1980 when the outside air-supply damper was closed. They were found to be well below the maximum accepted occupational standard of 0.50 per cent. The leakage air through the closed damper and air infiltration through the building fabric provided about 4.7 L/s per person, equal to the minimum value given in the ASHRAE Ventilation Standard 62-73. The comparison of the annual energy consumption data before and after operating the ventilation system with the outside dampers closed during the heating season indicated a substantial saving in fuel oil.

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The buildup of contaminants in the air in buildings is usually controlled by providing a continuous supply of "fresh" air and exhausting an equal amount of "used" air from the building. This supply of fresh air has to be heated in cold weather and thus contributes to the heating load of the building. There is an incentive, therefore, to use only as much fresh air as is actually needed to control the buildup of contaminants. A recent study of a high school in California (1) found that reducing the ventilation rate from 6.3 L/s to 0.72 L/s per person resulted in no adverse changes in the level of air contaminants measured (odour, ozone, colony forming particles, nitrogen oxides) except for carbon dioxide, which increased but still remained below 0.20 per cent. In some buildings, ventilation systems are being operated with the outside air supply dampers completely closed during the winter, relying on air leakage through the closed dampers and through the building envelope for outdoor air supply.

The Carleton Board of Education is operating some of their schools with the fresh air dampers closed in cold weather. The Board was willing to cooperate with DBR/NRC in measuring the conditions that prevailed in one of these schools. Tests were conducted in the Greely Public School (Figure 1), an open plan building located near Ottawa. The building is heated with an all air recirculating heating system with variable fresh air intake. Previous to 1978, the outdoor air damper was kept at a minimum open position unless the mixed air temperature of the ventilation system rose above 20°C. The flow rate of outside air at the minimum open position was not known. During and after 1978, the control system was altered to close the outside air-supply dampers when the outside air temperature dropped below 1.6°C and to operate normally above this temperature.

The purpose of the test was to obtain concentration profiles of CO_2 in the school generated by the occupants through respiration while the building was being operated with the outside air-supply dampers closed during winter. The concentration of oxygen was not measured for its depletion because the requirement for the amount of fresh air necessary for proper physiological functions is much less than that required to limit the concentration of carbon dioxide. The measurements obtained in February of 1980 are herein reported.

MEASUREMENTS

The floor plan of the Greely Public School, constructed in 1971, is shown in Figure 2. It is a single storey building with open-plan classrooms serving students from kindergarten to Grade 5 ranging in age from 5 to 11 years. The floor area, excluding the gymnasium and based on the inside dimension, is 1440 m^2 and the volume is 5,700 m^3; those of the gymnasium are 217 m^2 and 1,390 m^3. The total population of the school is 11 adults and 162 students of which 23 are in the kindergarten class and attend the morning session only. The main teaching areas are the north and south classrooms connected by a library reference room.

Except for the hot water convector units in the vestibule entrances and an electrical resistance heater in one office, the school is served by two all air systems; one for the classrooms, library, offices and other rooms, and the other for the gymnasium. The hot water for the main and reheat coils is heated by a boiler fired with No. 2 fuel oil. Because of malfunction, the humidifier in the ventilation system was not in operation during the heating season. The washroom and other exhaust fans are turned on at about 8:15 a.m. and switched off at about 4:30 p.m.

Air sampling taps were installed in the branch duct of the return air grill of the south and north classrooms (Figure 3) and in the main return and supply air ducts. These taps were connected by 0.60 cm plastic tubing to the sampling scanner of the CO_2 recording equipment (Figure 4) located in the south classroom. The concentration of carbon dioxide at each sampling tap was measured with a nondispersive type infrared gas analyzer and recorded on a strip chart recorder. The analyzer was zeroed with nitrogen gas and calibrated with a gas of known concentration (0.396 per cent) once each day. The CO_2 concentration was monitored for one week with the outside air-supply damper closed. To compare the carbon dioxide concentration in the room and in the branch return air duct, air samples were taken in the south classroom at 0.91, 1.5 and 2.1 m above floor level and 5.5 m away from the return air grill. The rate of outside air intake was calculated from air velocity readings in the supply air duct taken with a hot wire anemometer. The inside temperature and relative humidity were measured with thermohygrographs placed in the north and south classrooms.

RESULTS AND DISCUSSIONS

The CO_2 concentration profiles in the building for a typical day with the outside air-supply damper closed are shown in Figure 5. The outside air-supply rate measured with a hot wire anemometer was 344 L/s or 2.0 L/s per person which was about 10 per cent of that with the outside damper wide open. The initial concentration at the start of the school day was 0.036 per cent. The CO_2 concentration in the main return air duct, with branch air ducts connected to the various occupied spaces, can be considered as the average concentration in the school. The concentration in the branch return air duct of the south classroom with older students (Grades 4 and 5) was generally higher than that of the main return air, whereas the concentration of the north classroom with younger students fluctuated above and below the return air concentration. The concentration in the air-supply duct diluted by the intake of outdoor air was less than that of the return air. The effect of students leaving the school during recesses and lunch periods is evident from the dip in the concentration curves caused by the reduction in the indoor generation of CO_2 and increased infiltration rate with traffic through the entrance doors. Also, the space volume effect is evident by the buildup of CO_2 during the early part of the day. The comparison of the CO_2 concentrations in the south classroom at 0.91, 1.5 and 2.1 m above floor level and in the branch return air duct to that room were found to be about the same. This indicated a high degree of mixing in the room.

Table I gives the maximum and average concentrations of carbon dioxide recorded during the test period. With the outside air-supply damper closed, the leakage flow through the damper varied from 270 to 370 L/s. The maximum CO_2 concentration of 0.12 per cent was recorded in the south classroom and 0.096 per cent in the main return air duct. The corresponding average values were 0.090 and 0.078 per cent respectively. These values were well below the acceptable maximum limit of 0.50 per cent.

The dilution equation applicable to the changes in the concentration of the carbon dioxide generated in an occupied space is:

$$C = \left(C_s + \frac{G}{K(q_i+q_v)}\right)\left(1 - e^{-\frac{K(q_i+q_v)t}{V}}\right) + C_o\, e^{-\frac{K(q_i+q_v)t}{V}} \qquad (1)$$

C = carbon dioxide concentration in an occupied space at time, t, percent concentration by volume of CO_2 in air

C_o = carbon dioxide concentration at t=0, percent concentration by volume of CO_2 in air

C_s = outside carbon dioxide concentration, percent concentration by volume of CO_2 in air

G = volume generation rate of carbon dioxide, m^3/s

K = mixing factor (K=1 is perfect mixing and K=0 is non-mixing)

q_i = volumetric flow of infiltration air , m^3/s

q_v = volumetric flow of outside air through the ventilation system, m^3/s

t = time, sec

V = volume of space, m^3

At steady state, i.e., when $t = \infty$

$$C = C_s + \frac{G}{K(q_i+q_v)} \qquad (2)$$

If the generation rate is zero then the decay of carbon dioxide with time gives

$$\frac{q}{V} = -\frac{1}{K}\ln\left(\frac{C_1-C_s}{C_2-C_s}\right) \Big/ \; t_2 - t_1 \qquad (3)$$

where $\frac{q}{V}$ is the air change rate per unit time.

A similar expression applies for any other contaminants not absorbed by filters, structures and furnishings or those that do not settle as particulates.

The air change rates were calculated from the decay curve of carbon dioxide of the main return air duct recorded after the students left the school at 3:00 p.m. The values given in Table II were calculated from Eq. (3) assuming a value of mixing factor K = 1 (perfect mixing). With the outdoor air-supply damper closed, the air change rates (air leakage through closed damper and building fabric) varied from 0.50 to 0.66 air change per hour corresponding to 795 to 1050 L/s (4.60 to 6.0 L/s per person), which was much higher than the outdoor air-supply rate, through a closed damper, of 270 to 370 L/s. The difference between the air change rates as determined from the CO_2 decay curve and the outdoor supply air rate through the closed damper can be attributed to air infiltration through the building fabric induced by temperature difference and wind forces and the operation of the washroom and other exhaust systems. Assuming that the rates of air infiltration and outdoor air-supply are additive, (outdoor air-supply rate and exhaust rate of the ventilation system are balanced), the air infiltration rates varied from 0.29 to 0.49 air changes per hour; the average value was 0.35.

The carbon dioxide concentrations recorded in the supply and return air ducts of the ventilation system serving the gymnasium are shown in Figure 6. Measurements were made for one day only with the outside air-supply damper closed. The rate of leakage flow through the closed damper could not be measured. The air was supplied to the gymnasium from overhead diffusers and exhausted from the return air grilles located just above floor level. Maximum concentrations were below 0.10 per cent.

Figure 7 shows the outdoor and indoor humidity ratios with the damper closed for six consecutive days, during which time the indoor humidity ratio remained well above the outdoor humidity ratio at all times, apparently caused by the moisture generated by the school occupants being absorbed by the building structure and furnishings and released from them during unoccupied periods. In contrast, the CO_2 concentration had decreased to the outdoor level by midnight of each school day. The indoor relative humidity varied from 20 to 30 per cent during the test period.

The oil consumptions expressed in MJ/m^2 and corrected to the average Ottawa degree days of 4780°C and electricity consumption for the calendar years of 1977, 1978 and 1979 were:

	Fuel Oil MJ/m^2	Electricity MJ/m^2
1977	1550	243
1978	1325	260
1979	980	243

The change in the operation of the ventilation system was made in 1978 when the outside air-supply damper was scheduled to close below an outside temperature of 1.6°C. Comparison of the 1977 and 1979 figures indicates a 36 per cent reduction (27,400 L) in oil consumption with the outside air-supply damper closed during cold weather. The electricity consumption for the three years remained about the same. No other energy saving measures are known to have been made since 1978 except for improving the efficiency of the two boilers by about 2% each in 1979.

Where the outdoor air-supply rate cannot be measured with any precision, and the infiltration rate is not known, measurement of CO_2 in a space occupied by non-smokers of various age groups and activities can be used to adjust the outdoor air-supply damper to a suitable minimum position and to demonstrate the need to tighten up the building envelope in order to reduce air infiltration. More information, however, is required in relating concentration of CO_2 generated by occupants to the odour level in a room. For spaces occupied by smokers, other air contaminants, as well as CO_2, should be measured. It should be pointed out that CO_2 measurement relates only to air contaminants generated by occupants and does not indicate levels of air contaminants generated by building components, furnishings and processes.

SUMMARY

CO_2 concentrations measured in the test school while the outside air-supply damper was closed indicated that the maximum value of CO_2 recorded in the classroom during the test period was 0.12 per cent and the corresponding maximum average value of 0.091 per cent. These are well below the acceptable occupational limit of 0.50 per cent. The leakage flow through the closed damper and air infiltration through the building fabric provided outdoor air to the occupants at a rate of about 4.7 L/s per person, equal to the minimum value given in the ASHRAE Ventilation Standard 62-73(2) for classrooms. The fuel consumption data indicated that closing the damper during the heating season resulted in a substantial saving of fuel for this school.

ACKNOWLEDGEMENT

The author is indebted to the Carleton Board of Education for permission to carry out this study and to the staff of the Greely Public School for their assistance during the test. He also gratefully acknowledges the contribution of L. Jones in discussions on the energy consumption of the test school and for reviewing this paper, the assistance of R.G. Evans and R. Adm in the field tests, and of G.L. Johnson in carrying out trial computer calculation of heating loads.

REFERENCES

1. J.V. Berk, C.D. Hollowell, C. Lin and I. Turiel, The Effect of Reduced Ventilation on Indoor Air Quality and Energy Use in Schools. LBL-9382, June, 1979.

2. ASHRAE Standard 62-73, Standard for Natural and Mechanical Ventilation.

TABLE I

MAXIMUM AND AVERAGE CARBON DIOXIDE CONCENTRATIONS

Date Feb. 1980	Outdoor Air Supply Damper Position	Outdoor Air Supply Rate		Carbon Dioxide Concentration							
				Return		Supply		South Room		North Room	
				Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.
		L/s	(cfm)	%	%	%	%	%	%	%	%
13	Closed	350	(740)	0.096	0.078	0.089	0.076	0.123	0.090	0.104	0.082
14	Closed	340	(730)	0.095	0.079	0.090	0.075	0.122	0.091	0.103	0.081
15	Closed	370	(790)	0.080	0.069	0.075	0.066	0.112	0.080	0.083	0.069
18	Closed	270	(575)	0.085	0.070	0.080	0.066	0.100	0.076	0.093	0.072
19	Closed	330	(700)	0.085	0.071	0.079	0.066	0.105	0.082	0.093	0.074

TABLE II

AIR CHANGE RATES CALCULATED FROM CO_2 DECAY CURVE

Date Feb. 1980	Outdoor Air Supply Damper Position	Outdoor Air Supply Rate		Total Air Change* From CO_2 Decay			Outdoor @ 1530 Hr			
							Temp		Wind	
		L/s	(cfm)	AC/hr	L/s	(cfm)	°C	(°F)	km/hr	(mph)
13	Closed	350	(740)	0.51	810	(1700)	-3.5	(26)	17	(10.5)
14	Closed	340	(730)	0.50	795	(1680)	-2.0	(28)	12	(7.5)
15	Closed	370	(790)	0.56	890	(1880)	-7.0	(19)	9	(5.6)
18	Closed	270	(575)	0.66	1050	(2200)	-4.0	(25)	26	(16.1)
19	Closed	330	(700)	0.57	900	(1900)	-6.0	(21)	10	(6.2)

* K = 1.00 (mixing factor)

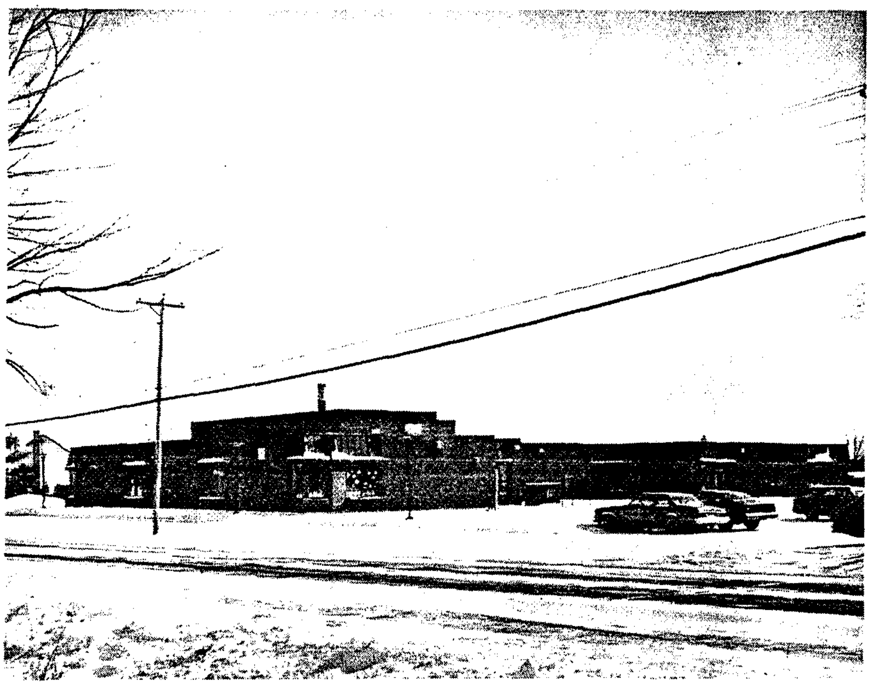

Figure 1 Test school

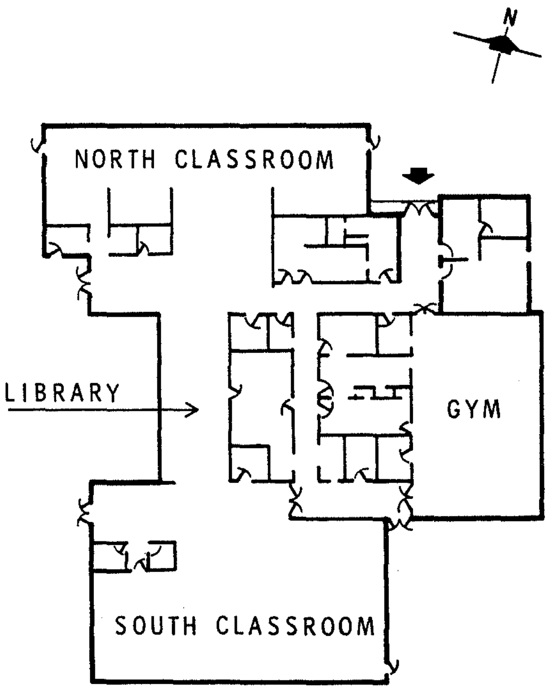

Figure 2 Floor plan

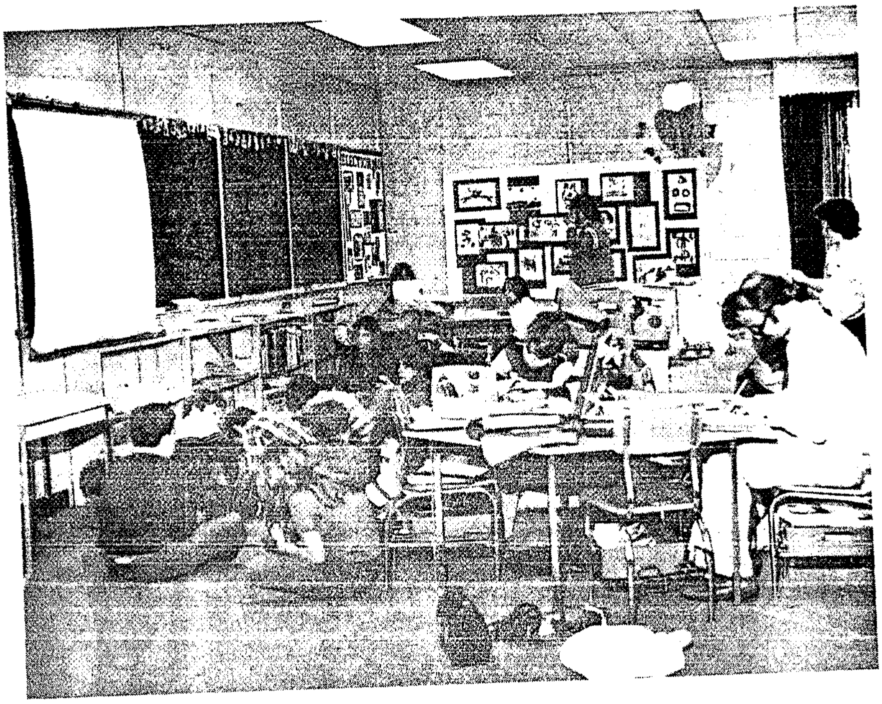

Figure 3 South classroom

Figure 4 Carbon dioxide monitoring equipment

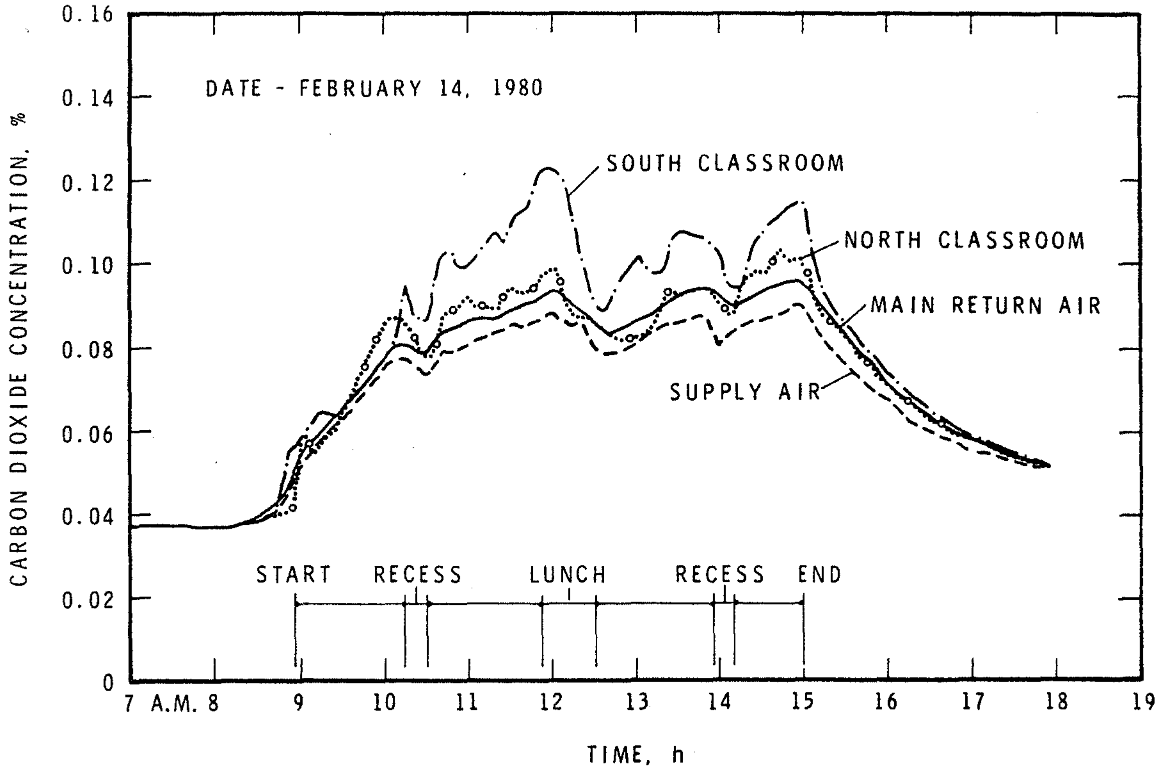

Figure 5 Carbon dioxide concentration vs time, outdoor supply-air damper closed (730 cfm)

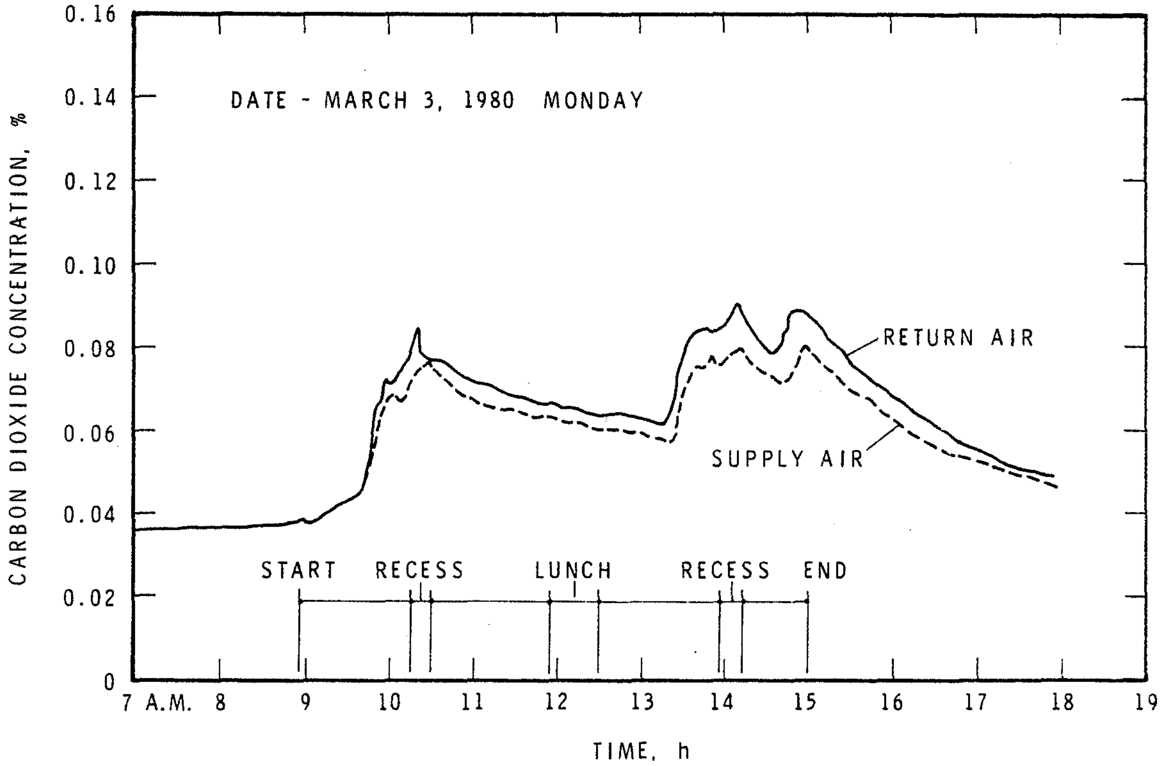

Figure 6 Carbon dioxide concentration in gymnasium, outdoor supply-air damper closed

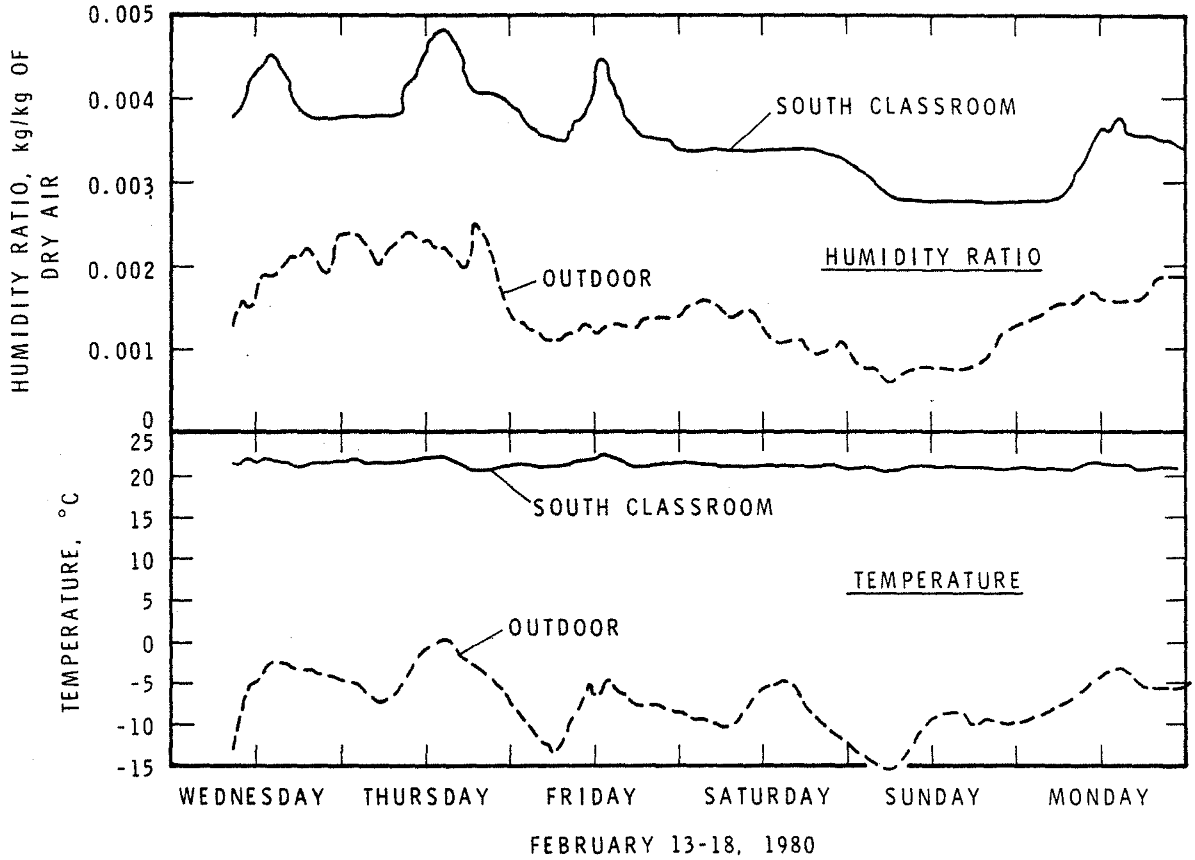

Figure 7 Indoor and outdoor humidity ratios and temperatures, outside supply-air damper closed.