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ASSOCIATIONS BETWEEN CLASSROOM CO_2 CONCENTRATIONS AND STUDENT ATTENDANCE IN WASHINGTON AND IDAHO

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ABSTRACT

Student attendance in American public schools is a critical factor in securing limited operational funding. Student and teacher attendance influence academic performance. Limited data exist on indoor air and environmental quality (IEQ) in schools, and how IEQ affects attendance, health, or performance. This study explored the association of student absence with measures of indoor minus outdoor carbon dioxide concentration (dCO_2). Absence and dCO_2 data were collected from 409 traditional and 25 portable classrooms from 22 schools located in six school districts in the states of Washington and Idaho. Study classrooms had individual heating, ventilation, and air conditioning (HVAC) systems, except two classrooms without mechanical ventilation. Classroom attributes, student attendance and school-level ethnicity, gender, and socioeconomic status (SES) were included in multivariate modeling. Forty-five percent of classrooms studied had short-term indoor CO_2 concentrations above 1000 parts-per-million (ppm). A 1000 ppm increase in dCO_2 was associated ($p < 0.05$) with a 0.5% to 0.9% decrease in annual average daily attendance (ADA), corresponding to a relative 10% to 20% increase in student absence. Annual ADA was 2% higher ($p < 0.0001$) in traditional than in portable classrooms.

PRACTICAL IMPLICATIONS

This study provides motivation for larger school studies to investigate associations of student attendance, and occupant health and student performance, with longer term indoor minus outdoor carbon dioxide concentrations and more accurately measured ventilation rates. If our findings are confirmed, improving classroom ventilation should be considered a practical means of reducing student absence. Adequate or enhanced ventilation may be achieved, for example, with educational training programs for teachers and facilities staff on ventilation system operation and maintenance. Also, technological interventions such as improved automated control systems could provide continuous ventilation during occupied times, regardless of occupant thermal comfort demands.

KEYWORDS
carbon dioxide, schools, children, ventilation, attendance

INTRODUCTION

Existing information on the relationships between indoor air and environmental quality (IEQ) in classrooms and student absence, health, or academic performance is limited and has been reviewed by Heath and Mendell (2002) and Daisey et al. (2003). There have been a few studies of the associations of student health, and to a lesser extent student absence or learning, with types of ventilation system, ventilation rates, indoor temperature and humidity, concentrations of chemical and microbiological pollutants, and amount of daylight (Pepler, 1968; Green, 1974, 1985; Norback et al., 1990; Ruotsalainen et al., 1995; Myhrvold et al., 1996; Myhrvold and Olsen, 1997; Smedje et al., 1997; Walinder et al., 1997a, 1997b, 1998; Meyer et al., 1999; Ahman et al., 2000; Smedje and Norback, 2000, Kim et al., 2002; Sahlberg et al., 2002; Heschong 2002). Some, but certainly not all, studies have found measured IEQ parameters were associated with health, performance, or absence.

Total ventilation, a combination of unintentional air infiltration through the building envelope, natural ventilation through open doors and windows, and mechanical ventilation, provides a means for reducing indoor concentrations of indoor-generated air pollutants. Ventilation standard 62 developed by ASHRAE (2001) specifies a minimum ventilation rate of 7.5 $L\ s^{-1}$ (15 $ft^3\ min^{-1}$) per occupant for classrooms. Ceiling- or wall-mounted heating, ventilation and air conditioning (HVAC) systems are often used to mechanically ventilate classrooms, although these HVAC systems may provide less ventilation than intended due to design and installation problems, poor maintenance, and because HVAC systems are often not operated continuously during occupancy.

Since measuring the actual ventilation rate is expensive and potentially problematic, the indoor concentration of carbon dioxide (CO_2) has often been used as a surrogate for the ventilation rate per occupant, including in schools (e.g., Lee and Chang, 1999). Indoor CO_2 concentrations exceed outdoor concentrations due to the metabolic production of CO_2 by building occupants. For example, for adult office workers, assuming a ventilation rate of 7.5 L s^{-1} per person and a typical outdoor CO_2 concentration of 350-400 parts-per-million (ppm), a steady state indoor CO_2 concentration of 1000 ppm has been used as an informal dividing line between "adequate" and "inadequate" ventilation (ASHRAE, 2001). However, a CO_2 concentration is only a rough surrogate for ventilation rate, primarily because the measured concentration is often considerably less than the steady state concentration. Despite the limitations of CO_2 concentrations as a measure of ventilation rate, higher concentrations have been associated with increased frequency of health symptoms and increased absence in studies of office workers (Erdmann et al., 2002; Milton et. al 2000). Available data have indicated many classrooms with ventilation rates below the code minimum or with CO_2 concentrations above 1000 ppm (e.g., Lagus Applied Technologies, 1995; Carrer et. al, 2002; Daisey et al., 2003; RTI, 2003; Shendell et al., 2003a). Therefore, the extent to which lower ventilation rates affect student health, absence, and performance is of particular interest. In general, school absenteeism can serve as an indicator of the student or teacher's overall health condition, although attendance patterns result from a complex interaction of many factors (Weitzman, 1986; Alberg et al., 2003).

This paper presents the results of a study which expanded the work of Prill et al. (2002), who reported findings from rapid IEQ assessment surveys in public schools, including short-term CO_2 measurements in the indoor air, outdoor air, and HVAC supply air diffuser. The present study's hypothesis explored if higher indoor minus outdoor CO_2 concentrations (dCO_2) were associated with increased student absence.

METHODOLOGY

Recruitment of classrooms

Primary and secondary schools in the states of Washington (WA) and Idaho (ID) were approached in the 2000-01 and 2001-02 school years to participate in the Washington State University (WSU) and the Northwest Air Pollution Authority (NWAPA) "3 Step IEQ Program," a streamlined approach for implementing the U.S. EPA's "Tools for Schools" program (Prill et al., 2002). These schools had attended IEQ workshops conducted by WSU or NWAPA, had contacted WSU or NWAPA for IEQ assistance, or were recommended to WSU and NWAPA by other participant school districts (SDs). To select our sample of schools from this group of K-12 schools (n=224), we used a two-step process. First, we only considered primary schools serving K-5 or K-6 (n=134), excluding special education and day care buildings. Second, due to limited resources and travel logistics, we focused on: 1) schools in cities or SDs with the most primary schools; 2) schools where the majority of classrooms were served by individual HVAC systems (or none if just wall heaters were used); and, 3) schools from which daily attendance data, at the student or classroom level, were available. Individual HVAC systems included wall- and ceiling-mounted unit ventilators or heat pumps for heating and/or air conditioning. We excluded classrooms in buildings where one HVAC system served multiple classrooms and classrooms with unvented space heaters for permanent heating systems. The goal of the selection criteria and exclusion policy was to ensure, to the extent possible, the classrooms including attic spaces were physically separated, with each served by their own mechanical HVAC system, and the environmental measurements conducted in each classroom were independent observations. The final study sample, after some schools could not participate because they lacked appropriate attendance data records, and given available resources, consisted of 436 classrooms from 22 schools (14 in WA, 8 in ID) in 6 SD (4 in WA, 2 in ID).

IEQ Assessments and CO_2 measurements

The IEQ assessments performed in every classroom consisted of walk-through surveys conducted by a technician together with relevant facilities and administrative staff, and short-term measurements of CO_2 during school hours (Prill et al. 2002). CO_2 measurements were conducted by WSU field technicians using the Q-TRAK Model 8551 instrument (TSI, Inc., Shoreview, MN, USA). Inside each classroom, two short-term measurements, each no more than a five-minute average, were conducted sequentially and the measurement times were recorded. First, indoor air CO_2 was assessed near the center of the classroom at the breathing zone height of seated students, but at least one meter from students and not directly underneath the supply air diffusers. Second, the CO_2 concentration in the HVAC supply air was measured using a capture hood to direct undiluted supply air into the instrument sensor. CO_2 instruments were calibrated weekly according to manufacturer specifications using “zero” (N_2, 99.99% pure) and “span” (2010 ppm CO_2, +/- 2%) gases. Instruments were also cross-compared during short-term (< five-minute average) outdoor air CO_2 measurements at each school at locations distant from potential CO_2 sources.

Attendance data

Attendance data were collected from school administrative staff who allowed field technicians access to school attendance records to enter data into a pre-formatted spreadsheet program. For seven schools of one SD, the enrollment and attendance of each individual student on each school day was recorded. For schools in every other SD, we recorded the number of students enrolled, the number absent, and the number in attendance for each classroom and school day. The daily percentages of students in attendance were calculated by pre-coded formulae. Attendance data received a quality control review by LBNL after WSU field technicians sent computer files. This process verified "0" or "blank" (student present) or "1" (student absent) was entered into every cell, vacation periods were left blank, file name room number and grade level designations matched those on the worksheet, and changes in enrollment during the school year were noted with gray-shaded cells. The average daily attendance (number of students attending class divided by number of students enrolled, then converted to a percentage) was calculated for the entire school year and is denoted by "annual ADA" or "yearly ADA." In addition, the same parameter was calculated for the portion of the school year prior to the IEQ inspection and is denoted "pre-visit ADA" or "pre-visit attendance." Although the pre-visit ADA was based on less data than the annual ADA, it was also not affected by any post-inspection ventilation rate changes motivated by recommendations of the inspectors. Annual average absence was calculated as unity minus annual ADA.

Demographic and socioeconomic variables

Aggregate data were collected on demographic and socio-economic variables that could influence student absence and, thus, confound the study findings. These data were obtained for the 2001-02 school year or based on the 2000 national census data available from several public electronic resources[1]. Ferris et al. (1988) reported data on gender and age (grades) helped explain observed variance in absenteeism. Haines et al. (2002) found the percentage of students in a grade level eligible for subsidized (free) meals at school was related to the average socio-economic status (SES) of the school enrollment in that grade. We collected data, at the school level, on gender and ethnicity (five categories). We also collected school-level data on percent participation in subsidized free lunch programs, reduced-cost lunch programs, and the composite

[1] ID Department of Education (http://www.sde.state.id.us); WA Office of the Superintendent for Public Instruction (http://www.k12.wa.us/edprofile, http://www.k12.wa.us/ → OSPI Programs → child nutrition, data administration, demographics, statistics); National Center for Educational Statistics (http://nces.ed.gov/ccd/schoolsearch).

of the free and reduced-cost lunch programs; the composite was used as an indicator of student SES.

CO_2 metric

Based on the measured CO_2 data, we computed the difference between the measured indoor and outdoor CO_2 concentrations (dCO_2). Previous research on CO_2 in school classrooms (Fox et al., 2003) demonstrated a single monitoring location was appropriate for characterizing such indoor contaminant levels when HVAC systems were on, i.e., air was well-mixed. The dCO_2 is only a rough surrogate for ventilation rate because it is based on one-time short-term measurements made at a wide range of times throughout the school day. The major advantage of dCO_2, relative to a ventilation rate estimate, is dCO_2 does not rely on any other assumptions. We made a thorough attempt to use the measured indoor CO_2 concentration and measurement time data to estimate the total ventilation rate, the flow rate of outside air into the classroom on the day of the CO_2 measurement prior to the measurement, by applying the transient mass balance equation. This approach, however, required several assumptions to be made, including for the calculation of the student indoor CO_2 generation rate, which varied by age (grade) and activity level. For details and related results, readers are referred to this study's final report available to the public through LBNL (Shendell et al., 2003c).

Multivariate Analyses

The data were analyzed with SAS software (Enterprise Guide version 1.3 and SAS system release 8.2, SAS Institute, Cary, NC). Descriptive statistics were calculated and the associations of independent variables with student attendance or absence were determined using multivariate linear regression models (ANOVA, PROC GLM). Models were developed for annual ADA, pre-visit ADA, and annual average absence as dependent variables. Independent variables in the final models were: 1) dCO_2, as a continuous variable; 2) the composite percentage of students at a school participating in subsidized free and reduced-cost lunch programs as an indicator of student and family SES; 3) grade level; 4) type of classroom – traditional or portable; 5) the state in which the classroom was located; and 6) the percentages of Hispanic and/or White/Caucasian students in the school as indicators of ethnic composition. Ideally, since multivariate linear regression requires observations to be independent, data on the SES indicator variable and the race/ethnicity variable at the classroom level instead of at the school level would have been preferred. This unavoidable limitation of the study's database was due to both the retrospective nature of attendance and potential confounder data collection and, more importantly, the reality that participant SDs only release these types of demographic data for public use at the school level due to confidentiality issues and political sensitivities. Nevertheless, visits to the SDs suggested variability within schools was much less than between schools for these two potential confounder variables.

Depending on the terms in the model, certain data were excluded because the values of one or more input parameters were missing. The two classrooms in WA with no mechanical HVAC system and the five classrooms with students in more than one grade level were excluded.

RESULTS

Descriptive Statistics

The average primary school was about 45 years old and most (94%) classrooms were in the main building, i.e., traditional, not portables. There was a fairly equal distribution of classrooms visited across the seven grades except 6th grade classrooms were visited relatively less often because many primary schools in our study only included K-5th grades (Table 1). Visits to study classrooms were fairly well distributed throughout the school day, although the least number of visits occurred during unoccupied periods (Table 1). Overall, about 19 of every 20 classrooms in this study were found with the HVAC system on or cycling automatically between on or off. About nine of every 10 classrooms visited were found with windows to the outside closed. In this study, 45% of visited classrooms had measured short-term indoor CO_2 concentrations above 1000 ppm (59% in ID and 35% in WA). Across states, grades, and room types, the geometric mean annual absence was 5% (median 4.9%, arithmetic mean 5.2%); the mean and median annual ADA were 95%.

Table 2 presents descriptive statistics for dCO_2 and ADA by state and room type. In ID, the average, median, minimum, and estimated 90th percentile dCO_2 values were higher in portable than traditional classrooms. In WA, average dCO_2 was slightly higher and maximum and estimated 90th percentile values were higher in portable than traditional classrooms; however, the median and minimum values were higher in traditional than portable classrooms. Average and median values for "yearly" and "pre-visit" ADA, which were similar, were higher in traditional than portable classrooms, slightly higher in ID than WA traditional classrooms, and higher in WA than ID portable classrooms.

Table 3 summarizes descriptive statistics for selected short-term CO_2 measures and attendance data by state, room type, and school to provide insight into within-school versus between-school variability. Within-school variability was evaluated by examining the standard deviations and ranges (minimum-maximum) of measured values. Between-school variability was evaluated by comparing the average and median values, and the ranges of measured values. The study data suggested considerable variability within most schools across states and room types, especially in ID, where ranges of dCO_2 values were generally higher. Across states among traditional classrooms, and WA portables, the data again suggested variability in dCO_2 values. For ID portables, the average and median values were similar between schools, though minimum and maximum values differed, likely due to small sample sizes (two schools, 3-4 classrooms at each). Across states and room types, the data suggested variability in annual ADA between schools since the ranges of average and median values, which were similar, were 2-4%. Idaho portables showed relatively more variability between schools, which again may be due to small sample sizes. Across states and room types, the data also suggested variability in annual ADA within most schools, and relatively more so in WA than in ID among traditional classrooms.

Table 4 presents descriptive statistics for dCO_2 by state, grade level (age), and room type. Across grades, average dCO_2 values were higher for traditional than portable classrooms in WA except for grade four, in part due to the small sample size of portables. In ID, average dCO_2 values were higher in portable than traditional classrooms across grades, and median dCO_2 values were similar across grades 1-6, which were higher than for kindergarten classrooms. In WA traditional classrooms, median dCO_2 values increased from kindergarten through grade six, except for a decrease at grade five. Across states and room types, except in WA grade 1 and grade 2-3 traditional classrooms and in WA portables for kindergarten and grades 2 and 3, where there were usually small sample sizes, maximum dCO_2 values were greater than 1000 ppm.

Furthermore, dCO_2 and short-term indoor CO_2 measurements in ID grade two portables were always above 1000 ppm. Overall, these observations on Table 4 were likely in part related to occupant densities and the ages of students as related to CO_2 generation rates (Shendell et al., 2003c), given WSU visits were spread across grades and school day hours (Table 1). Uncertainty included operations and maintenance practices at participating schools. Finally, by state, grade, and room type, variability in attendance and absence data (not presented) was observed as expected due to multiple factors such as susceptibility to illness by age, climatic conditions by season, sample sizes, and factors related to absence not assessed in this study.

<u>Results of multivariate analyses</u>

The primary results of the multivariate modeling are provided in Table 5. The final models included the most important variables, which were entered into the model at once (not stepwise), after examination of possible correlation between specific independent variables. The dCO_2 variable was statistically significantly ($p < 0.05$) associated with both the annual ADA and with the pre-visit ADA. For annual ADA, the parameter estimate indicated a 0.5% absolute decrease in attendance, corresponding to a 10% relative increase in the average 5% absence rate, per 1000 ppm increase in dCO_2. For the pre-visit ADA, the parameter estimate indicated a 0.9% absolute decrease in attendance, corresponding to a relative 20% percent increase in the average 5% absence rate, per 1000 ppm increase in dCO_2.

The traditional classroom type, relative to a portable classroom, was associated with approximately a 2% increase in attendance, and with a 2.5% decrease in absence. In each case, the associations were statistically significant ($p < 0.01$).

A one percent increase in the SES variable, representing the percentage of students receiving free or reduced cost lunch, was associated ($p < 0.001$) with a 0.03% to 0.04% decrease in attendance, and with a 0.02% increase in absence ($p < 0.001$). A one percent increase in the percent of Hispanic students was associated ($p < 0.02$) with a 0.03% increase in attendance, and with 0.05% decrease in absence ($p < 0.001$).

In most models, the state variable was not associated with attendance and the corresponding parameter estimate was unstable (results not included in Table 5). The most likely explanation for these findings was the present study only included two states.

DISCUSSION

In this study, 1000 ppm increases in the difference between indoor and outdoor CO_2 concentrations were associated with 10% to 20% relative increases in student absence, and the associations were statistically significant. These findings of this study are generally consistent with those of Milton et al. (2000), who found a 50% reduction in ventilation rates in offices, with corresponding increases in indoor CO_2 concentrations, was associated with a 50% increase in short term absence among the office workers occupying the buildings. One potential explanation for our findings and those of Milton et al. (2000) is lower rates of ventilation, indicated by higher CO_2, caused increased communicable respiratory illnesses, probably by increasing the indoor concentration of airborne infectious particles produced during coughing or sneezing. In a review of the literature, Fisk (2000) summarized three studies reporting a reduction in ventilation rate was associated with increases in confirmed respiratory illness.

Because the CO_2 measurements in this study were short-term, five-minute, measurements made on a single school day at variable times of day, they should be considered only rough surrogates for the long-term average classroom ventilation rates that may affect long-term average absence rates. In general, random[2] errors in an independent variable, in this case the errors from using short-term CO_2 as a measure of long-term average ventilation rate, will tend to obscure and weaken associations with the dependent variable (in this case, attendance or absence).

We are not aware of large uncontrolled sources of bias likely to create erroneous associations of higher dCO_2 concentrations with increased absence. The models contain variables controlling for SES, classroom type, grade level, ethnic composition, and the State in which the classrooms are located. Thus, we have controlled as well as possible, given data resources available to the American public, for obvious sources of confounding bias. However, it is still possible some unknown classroom factor, which increases absence rates, is positively correlated with the measured classroom CO_2 concentrations.

This study confirms previous findings of high CO_2 concentrations in classrooms, which indicated classroom ventilation rates were often below the minimum rates specified in codes. In this study, almost half of the CO_2 concentrations were above 1000 ppm and 4.5% were above 2000 ppm. If the measured CO_2 concentrations had been maximum or steady state values, a substantially larger proportion would be expected to exceed 1000 ppm. Thus, it is likely more than half of the classrooms in this study had ventilation rates less than specified in current minimum ventilation standards.

The substantially higher rate of absence in portable classrooms, relative to traditional classrooms, is notable. We do not have a clear explanation for this finding. It is not known whether portable classrooms have inferior IEQ relative to traditional classrooms. Recent evidence in Los Angeles County, however, has suggested relatively higher indoor air

[2] Errors that are not correlated with the value of the dependent variable

concentrations of toxic and odorous volatile organic compounds are possible in portable classrooms (Shendell et al., 2003b), as are higher occupant densities even if federal and state class size reduction initiatives apply across room types. In addition, it is not known whether inferior IEQ could cause such a large increase in absence. Although the higher absence rate in portable classrooms was statistically significant, the small sample (25 classrooms) should be considered. Before drawing conclusions, other studies should compare absence rates in portable and traditional classrooms.

Finally, we note how changes in ventilation or in any other factor affecting student attendance will influence the funding provided to many SDs, because funding is linked to annual ADA. For example, in California the most currently available (2001-02) funding rate is $12.08 per student-day not absent (CDE, 2003). For a classroom of 20 children with a 185-day school year (3700 student-days), a 1% decrease in annual ADA (or 20% relative increase in absence) is $450 per classroom in funding lost to the SD.

CONCLUSIONS

The major findings of this study were as follows:

- A 1000 ppm increase in the elevation of the indoor CO_2 concentration above the outdoor concentration was associated ($p < 0.05$) with a 0.5% to 0.9% decrease in yearly attendance, corresponding to a relative 10% to 20% relative increase in student absence.
- Yearly attendance was 2% higher ($p < 0.0001$) in traditional than in portable classrooms.
- Based on the measured CO_2 concentrations, we estimated ventilation rates in at least 50% of the classrooms were less than 7.5 L s^{-1} per person, which is the minimum rate specified in most codes and standards.

Since this study was based on analyses of previously collected CO_2 data, general conclusions should not be drawn from the observed linkage of higher CO_2 levels with increased absence. This study, however, does provide motivation for larger studies designed specifically to investigate the linkage of longer term CO_2 concentration data and more accurately measured ventilation rates with student absence.

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Table 1: Summary statistics of frequency of observations for selected qualitative variables.
Values presented are number of observations and percentage of observations (%).

	Time of visit and measures: school schedule variable[1]							
	early AM	AM recess	late AM	lunch	early PM	PM recess	late PM	not known
overall study	85 (21.2%)	9 (2.2%)	90 (22.4%)	39 (9.7%)	123 (30.7%)	11 (2.7%)	44 (11.0%)	35
WA only	23 (9.0%)	4 (1.6%)	68 (26.7%)	32 (12.6%)	93 (36.5%)	7 (2.8%)	28 (11.0%)	9
ID only	62 (42.5%)	5 (3.4%)	22 (15.1%)	7 (4.8%)	30 (20.6%)	4 (2.7%)	16 (11.0%)	26
	Grade (K, 1st to 6th)							
	K	1st	2nd	3rd	4th	5th	6th	other[2]
overall study	64 (14.8%)	70 (16.2%)	68 (15.7%)	67 (15.5%)	57 (13.2%)	61 (14.1%)	41 (9.5%)	8 (1.2%)
WA only	38 (14.6%)	43 (16.5%)	43 (16.5%)	41 (15.7%)	34 (13.0%)	38 (14.6%)	19 (7.3%)	8 (2.0%)
ID only	26 (15.1%)	27 (15.7%)	25 (14.5%)	26 (15.1%)	23 (13.4%)	23 (13.4%)	22 (12.8%)	0

[1] The values presented for this variable were coded as the categorical 1-7 ("." for not known) for statistical analyses in SAS Enterprise Guide v.1.3 (SAS v.8.2, Cary, NC).

[2] "other" meant the classroom was occupied by students in multiple grades (2nd and 3rd, or 4th and 5th) or the grade level varied and was not documented.

Table 2: Descriptive statistics for selected measures, with results presented by state and room type.

state	room type[1]	No. classrooms	No. obs. (no. missing obs.)	average	median	std dev	min	max	est. 90th %tile
dCO_2 (ppm), the short-term indoor minus school outdoor CO_2 concentration									
ID	M	165	164 (1)	840	670	630	50	4230	1460
ID	P	7	7	1510	1590	790	110	2440	2440
WA	M	244	239 (5)	580	570	310	60	3030	890
WA	P	18	16 (2)	610	300	850	10	3510	1140
annual average ("yearly") daily attendance (as %)[2]									
state	room type[1]	No. classrooms	No. obs. (no. missing obs.)	average	median	std dev	min	max	est. 90th %tile
ID	M	165	165	95.3	95.5	1.5	85.2	97.9	96.6
ID	P	7	7	91.0	92.4	3.5	87.0	95.1	95.1
WA	M	244	244	94.6	94.8	1.5	88.9	98.6	96.4
WA	P	18	18	93.3	93.4	1.7	89.8	97.0	95.1
average "pre-visit" daily attendance (as %)									
state	room type[1]	No. classrooms	No. obs. (no. missing obs.)	average	median	std dev	min	max	est. 90th %tile
ID	M	165	165	95.4	95.6	1.6	83.5	98.0	96.9
ID	P	7	7	90.4	93.0	4.6	84.7	95.0	95.0
WA	M	244	244	95.3	95.3	1.9	88.6	99.0	97.6
WA	P	18	18	93.9	93.6	2.0	90.8	98.3	96.5

[1] M = main building/traditional classroom, P = portable/relocatable classroom

[2] Annual average ("yearly") daily absence (as %) was calculated as 1 - "yearly" daily attendance (as %).

NOTE: WSU technicians did not record room type for two WA classrooms, thus were excluded.

Table 3: Descriptive statistics for selected measures, with results presented by state, room type and school to provide insight into within-school versus between-school variability.

					dCO_2, short-term indoor minus school outdoor						*school outdoor*	*annual average ("yearly") daily attendance*[3]					
state	room type[1]	school	No. classrooms[2]	No. obs. (no. miss obs.)	average	median	std dev	min	max	est. 90th %tile	average	average	median	std dev	min	max	est. 90th %tile
ID	M	A	11	11	1070	1190	480	310	1790	1590	410	94.1	94.0	1.0	92.2	96.2	94.9
		B	23	23	560	550	310	70	1200	970	380	95.7	96.0	1.0	93.3	97.0	96.6
		C	21	21	480	460	180	70	840	680	400	94.9	94.9	0.9	92.9	96.4	95.9
		D	23	23	1000	980	380	400	1630	1560	360	95.2	95.9	3.1	85.2	97.7	97.4
		E	20	20	510	340	540	50	2450	980	350	95.4	95.6	0.9	92.7	96.5	96.4
		F	26	25 (1)	590	610	280	180	1190	1060	450	96.0	95.9	0.7	94.9	97.9	96.7
		G	25	25	1670	1410	930	460	4230	3370	380	95.3	95.4	1.0	92.1	96.7	96.4
		H	16	16	810	720	250	550	1390	1320	400	94.9	94.8	0.9	93.4	96.6	96.1
ID	P	A	3	3	1540	1590	230	1290	1740	1740	410	93.2	93.0	0.9	92.4	94.1	94.1
		D	4	4	1500	1720	1100	110	2440	2440	360	89.3	87.6	3.9	87.0	95.1	95.1
WA	M	I	9	9	710	410	890	110	3030	3030	390	92.7	93.0	1.2	90.8	94.0	94.0
		J	16	16	810	790	120	610	1060	960	440	95.3	95.4	1.1	93.2	96.7	96.6
		K	14	14	440	400	150	210	710	680	380	94.1	94.5	1.3	90.0	96.0	95.0
		L	17	17	440	430	220	200	870	820	390	95.1	95.1	0.7	93.9	96.0	96.0
		M	19	19	460	410	200	150	1010	710	370	94.7	94.8	1.8	91.9	98.6	97.5
		N	20	16 (4)	570	530	270	130	1030	930	380	95.0	95.1	1.2	92.4	96.8	96.5
		O	13	13	560	630	290	60	1080	880	370	95.5	95.6	1.7	90.3	97.1	96.8
		P	22	22	460	500	210	130	1030	590	370	95.8	96.2	1.0	93.1	97.0	96.7
		Q	16	15 (1)	390	360	250	110	900	800	380	94.3	94.3	1.2	92.3	96.1	95.9
		R	24	24	670	600	210	370	1130	1020	380	94.1	94.4	1.6	88.9	95.8	95.5
		S	23	23	660	650	150	450	980	880	380	94.9	95.2	1.3	92.1	96.7	96.2
		T	20	20	690	680	140	400	910	870	360	93.9	93.8	1.2	90.9	96.3	95.3
		U	13	13	550	620	230	190	970	740	360	94.2	94.4	1.5	91.6	96.5	96.1
		V	18	18	690	500	540	260	2060	2010	350	94.2	94.7	1.5	90.8	96.9	96.2
WA	P	I	4	4	960	170	1700	10	3510	3510	390	91.9	92.0	1.6	89.8	93.8	93.8
		K	3	3	400	460	110	270	460	460	380	92.3	91.8	1.2	91.5	93.7	93.7
		L	2	2	330	330	250	160	510	510	390	94.8	94.8	0.4	94.5	95.0	95.0
		P	2	2	250	250	40	220	280	280	370	94.8	94.8	3.1	92.6	97.0	97.0
		S	2	2	990	990	120	910	1080	1080	380	94.4	94.4	0.1	94.3	94.4	94.4
		T	3	3	530	320	540	130	1140	1140	360	92.3	92.3	0.8	91.6	93.1	93.1

[1] M = main building/traditional classroom, P = portable/relocatable classroom
[2] Enrollment, attendance and absence data were available for each classroom included in analyses presented on this table.
[3] Annual average ("yearly") daily absence (as %) was calculated as 1 - "yearly" daily attendance (as %).

Table 3 (continued)

Table 4: Descriptive statistics for dCO_2 (in ppm) by state, grade level (age), and room type.

state	grade	room type[1]	No. class-rooms[2]	Arithmetic mean	Median	Standard deviation	Minimum	Estimated 90th percentile	Maximum
ID	K	M	26	570	440	410	70	1320	1410
WA	K	M	35	500	430	470	200	770	3030
WA	K	P	2	250	250	40	220	280	280
ID	1	M	27	820	680	480	250	1780	2130
WA	1	M	42	470	430	210	120	750	890
ID	2	M	22	1160	700	1030	210	2680	4230
ID	2	P	3	1540	1590	230	1290	1740	1740
WA	2	M	42	580	560	330	150	860	2060
WA	2	P	1	270	270	n/a[3]	270	270	270
ID	3	M	26	910	780	730	70	1430	3370
WA	3	M	40	600	610	320	60	880	2010
WA	3	P	1	460	460	n/a[3]	460	460	460
ID	4	M	23	790	680	520	50	1460	2290
WA	4	M	32	680	660	190	210	920	1010
WA	4	P	2	1980	1980	2160	460	3510	3510
ID	5	M	23	900	690	540	110	1680	2450
WA	5	M	33	580	570	240	110	920	1080
WA	5	P	5	410	320	410	10	1080	1080
ID	6	M	18	730	690	290	220	1130	1190
ID	6	P	4	1500	1720	1100	110	2440	2440
WA	6	M	14	810	760	150	650	1020	1130
WA	6	P	5	500	280	490	60	1140	1140
WA	2 and 3	M	2	610	610	400	330	890	890
WA	4 and 5	M	3	770	690	440	370	1240	1240

[1] M = main building/traditional classroom, P = portable/relocatable classroom

[2] Short-term indoor CO_2 (and thus dCO_2) data were missing for the following numbers of classrooms (n=6 total): grade 2, WA, M (n=1); grade 4, ID, M (n=1); grade 4, WA, M (n=1); and, grade 5, WA, M (n=3).

[3] n/a = not available because of small sample size (only one classroom) in this strata

Table 5. Key results of multivariate regression modeling.[1]

Basic Model Characteristics				CO_2 (per ppm)		room type variable [2]		SES variable[3]		ethnicity variable[4]	
No. of class-rooms	attendance or absence variable	CO_2 or vent. rate variable in model	Mod-el R^2	Parameter estimate	p-value	Para-meter estimate	p-value	Para-meter estimate	p-value	Parameter estimate	p-value
395	Yearly attendance%	dCO_2	0.21	-0.0005	0.02	2.29	<0.001	-0.026	0.0003	0.026	0.001
395	Pre-visit attendance%	dCO_2	0.18	-0.0009	0.001	2.33	<0.001	-0.037	<0.0001	0.029	0.02

[1]Parameter estimates represent percent increase in attendance or absence per ppm CO_2, 1 m^3 s^{-1} ventilation rate; or percent increase in the SES or ethnicity variable, or for a traditional classroom relative to a portable classroom. The P-values for the total model were always < 0.0001.
[2] For traditional/main building classrooms relative to portable/relocatable classrooms.
[3]The variable represented the percentage of students at the school receiving either free or reduced lunches.
[4]Percent Hispanic, in some models percent white/Caucasian was also included and significantly associated with attendance.