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Formaldehyde levels in traditional and portable classrooms: A pilot investigation

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Abstract

This pilot study assessed formaldehyde levels in portable classrooms (PCs) and traditional classrooms (TCs) and explored factors influencing indoor air quality (e.g., carbon dioxide (CO_2), temperature, and relative humidity). In a cross-sectional design, we evaluated formaldehyde levels in day and overnight indoor air samples from nine PCs renovated within three years previously and three TCs in a school district in metropolitan Atlanta, Georgia. Formaldehyde levels ranged from 0.0068 to 0.038 ppm. In both type of classrooms, overnight formaldehyde median levels (PCs = 0.018 ppm; TCs = 0.019 ppm) were higher than day formaldehyde median levels (PCs = 0.011 ppm; TCs = 0.016 ppm). CO_2 levels measured 470–790 parts per million (ppm) at 7AM and 470–1800 ppm at 4PM. Afternoon medians were higher in TCs (1,400 ppm) than in PCs (780 ppm). Consistent with previous studies, formaldehyde levels were similar among PCs and TCs. Reducing CO_2 levels by improving ventilation is recommended for classrooms.

Keywords

Indoor Air Quality; Schools; Formaldehyde; Carbon Dioxide; Ventilation; Furnishings

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Human Subjects Approval Statement: This pilot investigation was completed as a CDC Epi-AID to the State of Georgia and met all the CDC Human Subjects requirements.

BACKGROUND

During 1985-2008, public school enrollment increased from 39.4 million to 49.8 million in the United States (U.S.) (National Center for Educational Statistics (NCES), 2008), which led to overcrowding in some schools districts. A common response to overcrowding is to install temporary structures such as modular or portable buildings for use as classrooms. An estimated 33% (26,700 of 80,910) schools reported the use of portable classrooms in 2005. Over 350,000 portable classrooms are used throughout the U.S. (NCES, 2007).

Typical materials for building and furnishing portable classrooms, as well as new or modernized traditional school buildings, may off-gas formaldehyde, as well as other volatile organic compounds (VOCs), and result in exposures of public health concern (Hodgson, Shendell, Fisk, & Apte, 2004). Formaldehyde levels vary with type of construction materials, presence of pressed wood products, type of carpeting and flooring material, and efficiency of heating, ventilation and air conditioning (HVAC) systems. The release of formaldehyde from pressed wood products and other sources is known to decrease over time (Meyer, 1979). Studies consistently show that highest indoor formaldehyde concentration occur in new mobile homes and buildings, with values decreasing gradually over time (Sexton, Petreas & Liu, 1989; Norsted, Kozinetz & Annegers, 1985; Hanrahan, Dally, Anderson, Kanarek & Rankin, 1984). Additionally, formaldehyde emissions from indoors sources, such as plywood and particle board, increase with temperature and relative humidity, being highest in the summer months (Meyer, 1979).

Children have greater susceptibility to some environmental pollutants, including formaldehyde, than adults because they breathe higher volumes of air relative to their body weights and have actively growing tissues and organs (Faustman, Silbernagel, Fenske, Burbacher, & Ponce, 2000). Acute exposure to formaldehyde can result in irritation of the throat, nose, eyes, and skin (Agency for Toxic Substances and Disease Registry (ATSDR), 2010). Several observational studies have demonstrated associations between formaldehyde and asthma outcomes, such as increased bronchial responsiveness in children with asthma, emergency treatment for asthma, increased risk of IgE-mediated sensitization, and increased diagnoses of asthma (ATSDR, 2010). Indoor exposure to formaldehyde has also been associated with chronic respiratory symptoms and decreased pulmonary function among children (Krzyzanowski, Quackenboss, & Lebowitz, 1990). Nasal irritation, eye irritation, and increased risk of asthma and allergies have been observed at airborne formaldehyde levels at 0.01 – 0.5 ppm. Continuous exposure to formaldehyde also has led to increased IgE-mediated sensitization and symptoms at levels greater than 0.05 ppm, the World Health Organization's threshold, among primary schoolchildren (Wantke, Demmer, Tappler, Götz, Jarisch, 1996). Formaldehyde is also a human carcinogen (NTP, 2013).

Few published studies have examined formaldehyde levels in occupied portable classrooms, mainly from California, United States (Hodgson et al., 2004; Shendell, Prill, Fisk, Apte, Blake, & Faulkner, 2004; Shendell, Winer, Weker, Colome, 2004a; California Air Resources Board (CARB), 2003). Public health concerns about formaldehyde exposure during travel trailer and mobile home use following the Gulf Coast hurricane Katrina in 2005 prompted this investigation (Centers for Disease Control and Prevention (CDC), 2008). Our primary objective was to describe formaldehyde levels in portable classrooms (PC) and traditional classrooms (TC) occupied by school-aged children, a potentially sensitive population. Secondary objectives were 1) to develop and field test a noninvasive, nonintrusive, and non-disruptive sampling protocol to measure levels of formaldehyde during school hours and overnight; and 2) to explore factors that may influence indoor air quality, such as use of HVAC systems, levels of CO_2, temperature, and relative humidity. To our knowledge, this is the first study assessing levels of formaldehyde in school classrooms in the southeastern US, where hot temperatures and high humidity characterize spring and summer months.

METHODS

Participants

The metro Atlanta School District participating in this study has nine PC units that were renovated within 3 years of the investigation. Twelve classrooms were sampled as follows: School A = four PC (Quad units) and one TC; School B = one PC and one TC; and School C = four PCs (each as an individual portable unit) and one TC. Because Quad units have four classrooms per unit, one classroom per unit was randomly selected at School A. The school district was selected by convenience and data were collected in the last week of the district's school year, May 18-21, 2009.

Procedures

Investigators pre-tested a standardized nine-page questionnaire with the school district's Indoor Air Quality (IAQ) Coordinator, who then distributed it to facility managers and teachers for recording indoor environment and classroom exterior characteristics. Teachers from PCs and TCs responded to questions about the HVAC system, such as noise level and use during class hours, air quality, and environmental conditions in the classrooms.

Two simultaneous 9-hour school day and two overnight 15-hour samples of formaldehyde were collected in each classroom, using the 1994 National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods, Method 2016, with Supelco® S10 LpDNPH cartridges (St. Louis, Mo). Samplers were positioned in opposite corners of the PCs and TCs within 10 meters distance. Teachers were requested to open or close doors and windows as they might during typical classroom instruction hours. Samples were collected using SKC, Inc. (Eighty Four, PA) Model 210 personal sampling pumps. Samples were drawn at a low-flow rate between 0.05 and 0.1 liters per minute, and the pumps were placed at a height of 1.2 meters. Air sampling pumps were calibrated before and after use with a Bios Dry Cal® calibrator primary standard. For day sampling, pumps were started immediately prior to the beginning of the school day (i.e., the arrival of the students at 7 AM) and stopped after the end of the school day (around 4 PM). For overnight sampling, pumps were operated after the school day ended (4 PM) and stopped in the morning prior to the school day's start (7 AM). One outdoor and one field blank sample were collected on each sampling day (four days) in the field from all three schools. Field blanks are used as part of quality control procedures and no contamination was observed during handling. All sample tubes were stored in a freezer or in a cooler on ice at all times when not being used for sampling. At the end of each sampling day, sample cartridges were resealed using cartridge plugs, and placed in a re-sealable pouch. Samples were transported to a refrigerator and shipped to the designated analytical laboratory (Bureau Veritas, Novi, Michigan) in coolers via overnight express.

Concurrent (day and overnight) measurements of indoor temperature and relative humidity were conducted in each classroom using HOBO® U23 dataloggers. CO_2 was measured in each classroom at the start (7 AM) and at the end (4 PM) of the school day by use of TSI, Inc Q-TRACK™. Temperature, relative humidity, and outdoor CO_2 were also measured in all three schools; CO_2 levels were used as indicators of classroom ventilation.

Strict quality assurance/quality control (QA/QC) procedures were observed including the use of chain of custody forms (NIOSH, 1994). To ensure schools' privacy and safeguard data, each PC or TC was assigned a unique identifier number linked to data recorded on paper interview and abstraction forms. Laboratory samples were analyzed using specific standard QA/QC procedures (NIOSH, 1994) for an American Industrial Hygiene Associated-accredited laboratory.

The primary outcome variable was the one entire school day concentration of formaldehyde measured in PCs and TCs. The average between the two formaldehyde samples from each classroom was used to calculate the overnight and day means and medians for over the four days of testing. Data on potential factors that might affect the formaldehyde levels were collected, including indoor temperature, indoor relative humidity, and CO_2 concentration. Other classroom characteristics, such as window and/or air conditioning use, time spent in classroom, age of construction or renovation of the portable classroom, exterior temperature, and direction of prevailing wind during the sampling days, were also collected.

Data analysis

Data were analyzed using SAS version 9.1. Differences in means were tested for statistical significance using the unpaired Student *t* test. Statistically significant differences in proportions were determined using the chi-square test. Since samples are small and the distribution of concentrations is unknown, differences in means and proportions were also analyzed using non-parametric methods, with no change in findings or conclusions (data not shown). Results were considered statistically significant at $p<0.05$.

RESULTS

Three schools participated in this pilot study, two elementary—including pre-kindergarten aged children—and one high school. None of the studied classrooms were adjacent to a laboratory, an industrial building, an art shop, or other special purpose rooms. Building characteristics for portable and traditional classrooms for all three schools (A, B, and C) are shown in Table 1. Even though only PCs in school A were built three or less years prior to this pilot study, all PCs were considered new because PCs in schools B and C had been fully renovated (with completely new interior) within three years from the beginning of the study, and were acquired one year before the study. All TCs were built more than 3 years prior to the study and had not been renovated. With the exception of the TC in school C, no classrooms had interior items replaced in the last three years before this study, or since they were built new or renovated. Building construction materials such as roof, interior and exterior walls, were similar among same type of classroom, but differed between PCs and TCs. The composition of classroom furnishings was similar across all PC and TC units sampled. Tables and desks were mostly a combination of solid and pressed wood, plastic, and metal, while bookcases, cabinets, and chairs were made primarily of solid and pressed wood. Floors in all PCs and in one TC (school B) were entirely carpeted and two TCs had concrete flooring. Finally, all twelve classrooms featured windows on only one side of the classroom.

On average, 23 students occupied both PCs and TCs, with 83 percent typically changing rooms during the day, with the exception of two classrooms—one PC and one TC—where students stayed all day. The average time students spent inside the same classroom was 1.8 hours for PCs and 4.2 hours for TCs. Teachers typically spent six or more hours in the same classroom five days per week. Among the five classrooms with doors opening directly to the outdoors (all portable classrooms), teachers of three classrooms reported occasionally leaving the door open during the school day. Of twelve teachers, five reported occasionally opening the classroom windows for natural ventilation. Each of the twelve classrooms had functioning air conditioning units and a thermostat; only one traditional classroom teacher reported not being able to adjust the thermostat because it was locked. Two teachers reported turning off the air conditioning frequently, and two reported turning it off occasionally.

At the time the samplers were placed inside the classrooms (7 AM for day and 4 PM for overnight measures), none of the classrooms had open windows or exhaust vents and the AC was on only in two PCs and one TC at the beginning of the overnight sampling period, and in one PC at the beginning of the day sampling period. Four of 48 formaldehyde samples were void during the sampling period due to battery pump failure (three during the day and one overnight). Overall, across schools (A, B, and C), classroom types (portable, traditional), and sampled period (overnight, day), measured levels of formaldehyde ranged from 0.0068 ppm to 0.038 ppm with a median of 0.017 ppm. Figure 1 illustrates measured overnight and day formaldehyde levels in all twelve classrooms. No statistically significant differences were observed when comparing formaldehyde levels in TCs versus PCs for daytime ($t(10) = -0.05$, p value = 0.96) or overnight ($t(10) = -0.43$, $p=0.68$) periods (TCs shown in light gray box). School A consistently presented the highest concentrations of formaldehyde across sampled period and classroom type. School C presented the lowest levels among the PCs. The overall variability in formaldehyde concentrations in schools A and B was greater than in school C, respectively (SD =0.010, 0.010, and 0.0048 ppm).

Between-school variability, measured by comparing the average and median values and the ranges of measured values, was also substantially high. Median values, for both classroom types, in school A (0.031 ppm) were over twice as high as in schools B and C (0.011 and 0.012 ppm, respectively), and means were 0.027, 0.016, and 0.013 ppm for schools A, B, and C, respectively. The day average concentration of formaldehyde (ppm) was higher in TCs (0.019) than in PCs (0.016); however, the highest value was found in a PC (0.034) (Table 2). Overnight mean formaldehyde levels were similar for PCs and TCs. Both overnight mean and median levels were higher than day levels across the two types of classrooms but these differences were not statistically significant ($t(22)=1.24$, $p=0.23$). Day–

night differences among formaldehyde levels may be reflective of differences in classrooms' night-time HVAC settings.

Temperature and relative humidity (RH) exhibited small variations, compared to formaldehyde and CO_2 concentrations. Seven classrooms (3 traditional and 4 portable) had at least one of the measured indoor CO_2 concentrations above 1,000 ppm. Outdoor CO_2 concentrations were 380 ppm, 420 and 420 ppm at schools A, B, and C, respectively. Table 2 summarizes descriptive statistics (mean, median, SD, range) of day and overnight environmental measures. CO_2 AM and PM concentrations were significantly different ($t(22)=3.36$, $p=0.003$). However, the overall difference in CO_2 concentrations between PCs and TCs (including day and night measurements) were not statistically significant ($t(22)=-1.28$, $p=0.21$) (Figure 2). CO_2 day concentrations did not differ between PCs and TCs ($t(10)=-0.75$, $p=0.47$), nor did overnight concentrations between PCs and TCs ($t(10)=-1.46$, $p=0.18$) (Figure 2). Temperature and RH median values were similar between PCs and TCs (Table 2). Indoor temperatures were higher overnight than during the day, and this finding was very similar among PCs and TCs. Measured indoor RH was higher during the day than overnight, and again, RH was fairly similar across the two types of classrooms.

DISCUSSION

Formaldehyde levels in PCs measured during this investigation were similar to those measured in TCs and those found in portable trailers in California (CARB, 2003), and below levels observed to result in eye and nasal irritation, and increased risk of asthma (ATSDR, 2010). The mean formaldehyde levels measured in a comprehensive study of air quality in portable classrooms conducted by the California Air Resources Board were 0.015 ppm for PCs (n=135) and 0.012 ppm for TCs (n=64); indoor CO_2 and humidity showed positive associations with formaldehyde levels (CARB, 2003). The measured levels of formaldehyde in air were below the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Value (TLV®) for formaldehyde of 0.3 ppm as a ceiling concentration not to exceed during the work day (ACGIH, 2001).

In this pilot study, teachers from PCs complained more about indoor noise, specifically noise produced by the HVAC system, than teachers from TCs and a few teachers reported having to turn the air conditioning off because of its excessive noise, a finding similar to that observed in the CARB study (CARB, 2003) (data not shown). Because HVAC systems tend to reduce indoor volatile organic compounds, including formaldehyde, among other chemical and microbiological potential sources of respiratory illness, it is important that these systems are well designed and functioning adequately. HVAC systems are often used to mechanically ventilate classrooms, although these systems may provide less ventilation than intended as a result of design and installation problems, poor maintenance, and infrequent operation during occupancy (Shendell, Winer, Weker, & Colome, 2004b).

Because measuring the actual ventilation rate requires specialized skill and equipment, the indoor concentration of CO_2 has been used as a surrogate for the ventilation rate per occupant, including in schools (Lee & Chang, 1999); Shaughnessy, Haverinen-Shaughnessy, Nevalainen, Moschandreas, 2006; Shendell, et al., 2004). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) developed consensus standards and a guideline for HVAC systems. The ANSI/ASHRAE 62.1-2007: "Ventilation for Acceptable Indoor Air Quality" recommends that indoor CO_2 concentrations be no greater than 700 ppm above outdoor CO_2 concentrations in order to satisfy comfort needs of the majority of occupants (ASHRAE, 2009). This standard corresponds to indoor levels less than 1080 ppm since outdoor CO_2 concentrations usually range between 380 to 410 ppm. NIOSH, 2008, states that "Elevated CO_2 concentrations suggest that other indoor contaminants may also be increased." The Occupational Safety & Health Administration's (OSHA) permissible exposure limit for indoor CO_2 is 5000 ppm (OSHA).

In this pilot investigation, elevated (>1,080 ppm) levels of CO_2 were observed, particularly in TCs, in concurrence with the findings of Shendell, et al. (2004) of lower ventilation rates in TCs than in PCs. Although the levels of CO_2 concentrations observed in this pilot study do not represent a health threat, this finding is noteworthy because lower rates of ventilation, as indicated by higher CO_2 concentrations, are known to be associated with increased respiratory illness (Fisk, 2000). In addition, high CO_2 concentrations have been associated with relative increases in students' school absence (Mendell, Eliseeva, Davies, Spears, Lobscheid, Fisk, & Apte, 2013; Shendell et al., 2004b) and lower performance (Haverinen-Shaughnessy, Nevalainen, Moschandreas, & Shaughnessy, 2010; Mendell & Heath, 2005). It might be noted that OSHA standards for exposure concentrations do not apply to children, who may be at greater risk to adverse effects from exposure to CO_2.

These results demonstrated the feasibility of conducting indoor air quality investigations in the school environment with minimal disruption on school days – the goal of the investigation. This pilot investigation has a number of limitations. First, the field team was allowed limited, fixed time on the schools' grounds and inside classrooms, a restriction reducing the ability to complete a comprehensive walk-through survey in classrooms. Because the data collection occurred in the last week of the school year, conditions may not have been representative of the whole year pattern, and such factors (e.g., attendance) could have affected the magnitude of measured indoor CO_2 concentrations. A 100 percent questionnaire response rate was attributed to a small sample size and the ability of the school system's IAQ Coordinator to follow up with facility managers and teachers. This questionnaire may be useful for conducting similar school air quality investigations, particularly for study designs involving larger sample sizes.

Because this pilot study was carried in only one school district, interpretation of results was limited to these parameters as well as a relatively small number of classrooms sampled and different configurations of classrooms in each school. Further, sampling newly manufactured portable classrooms which might be expected to off-gas more formaldehyde than older ones was not possible. Lastly, airborne particulate levels in PCs were not measured although classrooms often were located adjacent to particulate sources such as parking lots and roadways.

Conclusion

Consistent with previous findings, the levels of formaldehyde measured in PCs were similar to levels observed in TCs. Elevated levels of CO_2 were found in both PCs and TCs, indicating inadequate ventilation. On the basis of this work, we believe that a well-designed study of portable and traditional classrooms would be an appropriate effort that should not only examine formaldehyde levels and ventilation in portable classrooms, including CO_2 levels, but also address other potential factors affecting indoor environments in PCs and TCs. Upon acquisition or renovation of PCs, a school district is encouraged to access resources, such as the Environmental Protection Agency's Indoor Air Quality Tools for Schools Reference Guide and Design Tools for Schools (EPA, 2009, 2010).

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Location	Overnight	Day	Overnight	School Day
Ap	12	11	0.012	0.011
Ap	25	20	0.025	0.020
Ap	34	34	0.034	0.034
Ap	38	34	0.038	0.034
Bp	31	11	0.031	0.011
Cp	18	8.7	0.018	0.009
Cp	18	9.2	0.018	0.009
Cp	15	9.4	0.015	0.009
Cp	7.3	6.8	0.007	0.007
At	38	29	0.038	0.029
Bt	10	12	0.010	0.012
Ct	19	16	0.019	0.016

units
ug/m3

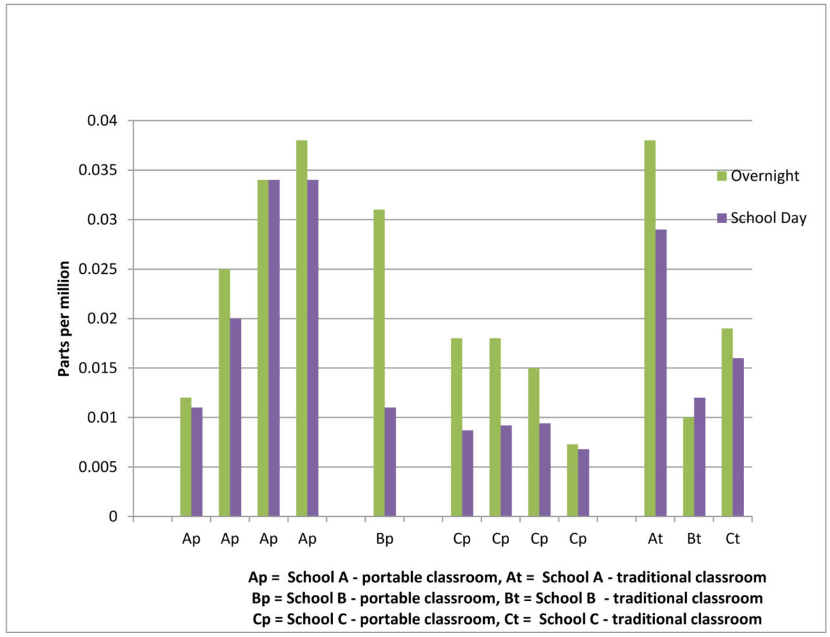

Figure 1.
Average Indoor Air Formaldehyde Levels In Portable and Traditional Classrooms

Location	7:00 AM	4:00 PM
Ap	472	527
Ap	579	776
Ap	517	1313
Ap	576	1819
Bp	481	532
Cp	645	901
Cp	676	574
Cp	512	1081
Cp	467	599
At	795	1044
Bt	541	1424
Ct	485	1416
Ao	379	386
Bo	531	352
Co	469	391

Ao

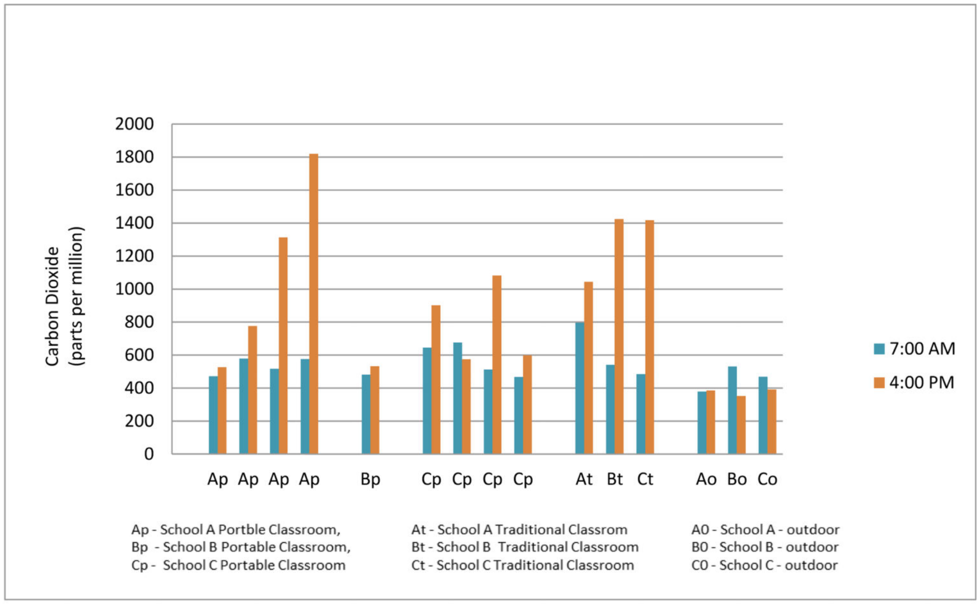

Figure 2.

Average Indoor Carbon Dioxide Levels in Portable and Traditional Classrooms

Table 1

Building characteristics of portable and traditional classrooms among study schools A, B, and C

Characteristics	School A Portable (n=4)	Traditional (n=1)	School B Portable (n=1)	Traditional (n=1)	School C Portable (n=4)	Traditional (n=1)
Acquisition status	New, ≤3 years before study	Built ≥3 years before study	New, renovated 1 year before study (originally built 15 years before study)	Built ≥3 years before study	New, renovated 1 year before study (originally built 10 years before study)	Built ≥3 years before study
Replacement status	---	No renovation	---	No renovation	---	Lighting, floor, and HVAC unit replaced in last 3 years
Roof composition	Synthetic rubber	Composite shingle or tar/gravel	Synthetic rubber	Composite shingle or tar/gravel	Synthetic rubber	Composite shingle or tar/gravel
Exterior walls composition	Concrete-based, mixed wood/ panel board, metal	Masonry	Concrete-based, mixed wood/ panel board, metal	Masonry	Concrete-based, mixed wood/ panel board, metal	Masonry
Interior walls composition	Vinyl-coated or gypsum dry wall	Painted cinderblock	Vinyl-coated or gypsum dry wall	Painted cinderblock	Vinyl-coated or gypsum dry wall	Painted cinderblock
Floor composition	Entirely carpeted	Concrete	Entirely carpeted	Entirely carpeted	Entirely carpeted	Concrete

Table 2

Day and overnight environmental measures distribution (mean, standard deviation (SD) and range) for portable and traditional classrooms

	Portable (n = 9)					Tradition (n = 3)				
Day	**Mean**	**Median**	**SD**	**Min**	**Max**	**Mean**	**Median**	**SD**	**Min**	**Max**
Formaldehyde (PPM)	0.016	0.011	0.011	0.0068	0.034	0.019	0.016	0.009	0.012	0.029
CO_2 (PPM) (1)	890	780	440	480	1800	1300	1400	216	1000	1400
Temperature (C)	21.4		1.4	19.5	23.4	22.3		1	21.3	23.3
RH (%)	48		10.6	37.7	69.7	47.3		10.3	38.8	58.8

Overnight	**Mean**	**Median**	**SD**	**Min**	**Max**	**Mean**	**Median**	**SD**	**Min**	**Max**
Formaldehyde (PPM)	0.022	0.018	0.011	0.0073	0.038	0.022	0.019	0.014	0.01	0.038
CO_2 (PPM) (2)	560	580	72	470	680	610	540	166	480	790
Temperature (C)	25.3		1.9	22.2	27.4	25.1		1.4	24.1	23.3
RH (%)	43.6		5.2	37.3	53.9	38.2		3.2	35.8	58.8

Footnotes

(1) CO2 measured at 4:00 PM

(2) CO2 measured at 7:00 AM

RH = relative humidity