Impact of Paint on Indoor Air Quality in Schools

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SUMMARY

The health and comfort of students and teachers are among the many factors that contribute to learning and productivity in the classroom, which in turn affect performance and achievement. Every effort is made to achieve good indoor air quality ("IAQ") through proper design, construction and operation of a school. A typical cause of poor IAQ is volatile organic compounds or "VOCs" that originate from construction materials, furnishings, and finishes. Many VOCs can produce objectionable odors and cause irritation such as headache, eye tearing, and nasal burning. Paint, a common product that contributes VOCs into the air, is frequently used to refresh school appearance and improve surface durability. The VOCs associated with paints and coatings (e.g., formaldehyde, aldehydes, benzene, toluene, and xylene) can be either ingredients that are added to the paint to enhance product performance and shelf life or they can be byproducts of the paint drying process.

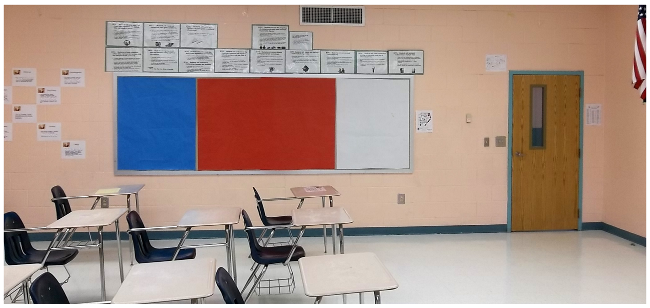
In the fall of 2011, UL-GREENGUARD conducted two demonstration studies at a public middle school in Savannah, Georgia, to evaluate the impact that different types of paints have on IAQ in educational environments. The studies were a collaborative effort among UL's GREENGUARD Environmental Institute, The Sherwin-Williams Company ("Sherwin-Williams"), the Georgia chapter of the U.S. Green Building Council, and the Chatham County (Georgia) School District. The primary objective of the first school demonstration study was to compare airborne levels of VOCs when a conventional semi-gloss paint was used on interior wall surfaces versus a formulation of low VOC semi-gloss paint (VOC ≤ 50 g/L). The low VOC semi-gloss paint was compliant with the GREENGUARD Children and Schools emissions criteria and also met the recommended California chronic reference levels ("CRELS") as traditionally specified in various green building programs. Airborne measurements of VOCs were made up to 14 days following painting. The data showed significant IAQ differences between the two paints studied in the school classrooms. The low VOC paint resulted in a greater than 90% reduction in total VOCs added to the air within 24 hours after application in comparison to the conventional paint. In addition, all of the VOCs associated with the low VOC paint were below detectable levels within 7 days whereas emissions of the conventional paint could still be observed in the air after 14 days.

The second school demonstration study evaluated the impact of using Sherwin-Williams enhanced Harmony® formulation with formaldehyde reducing technology (currently available in flat and eg-shel sheens) in school classrooms. Enhanced Harmony® Paint was specially formulated to help promote better IAQ by reducing airborne concentrations of formaldehyde and other aldehydes. Use of enhanced Harmony® Paint demonstrated a 45% reduction in a classroom airborne formaldehyde level whereas use of the conventional and low VOC semi-gloss paints did not demonstrate such a reduction. Additional laboratory studies confirmed airborne formaldehyde reduction with use of enhanced Harmony® Paint containing formaldehyde reducing technology.

KEYWORDS
VOC emissions; paint emissions; school study; VOC exposure

1 INTRODUCTION

IAQ in schools. Twenty percent of the U.S. population, or nearly 55 million people, spend their days in our elementary and secondary schools. Studies show that one-half of our nation's 115,000 schools have problems linked to IAQ. Young students in particular are at greater risk to exposure to indoor air pollutants because of the hours spent in school facilities, their biological susceptibility, and the inability to detect airborne hazards. Children breathe at a faster rate than adults; this coupled with their smaller body mass results in a higher dose of available pollutants for a child than an adult. Asthma remains the leading cause of school absenteeism and hospitalizations in children under the age of 15. In a recent study, for example, children aged 5 to 17 years with at least one asthma attack in the previous year missed 10.5 million school days in the aggregate that year.



The health and comfort of students and teachers are among the many factors that contribute to learning and productivity in the classroom, which in turn affect performance and achievement. Every effort is made to achieve good IAQ through proper design, construction and operation of a school. A typical cause of poor IAQ is VOCs that originate from construction materials, furnishings, and finishes. Many VOCs can produce objectionable odors and cause irritation such as headache, eye tearing, and nasal burning. Studies have shown that children exposed to high levels of VOCs are four times more likely to develop asthma than adults (Rumchev et al, 2004). Other studies also have found an association between VOCs and asthma in children (CARB, 2005). The US Environmental Protection Agency ("USEPA") and other public health advisories indicate one of the most effective ways of achieving good IAQ is "source control," which involves the selection and use of low VOC building materials and processes that contribute minimal VOCs into the air. Source control, in combination with good building ventilation and controlled cleaning practices, can significantly reduce indoor air pollution and improve overall IAQ.

Role of interior paints. Numerous products can contribute or off gas VOCs into the air including certain flooring types, cleaning chemicals, furniture, printers, ceiling systems, wall coverings, paint, adhesives and sealants, and art supplies. Paint products, a common source of VOCs, are frequently used to refresh school appearance and improve surface durability. The VOCs associated with paints and coatings (e.g., formaldehyde, aldehydes, benzene, toluene, and xylene) can be either ingredients that are added to the paint to enhance product performance and shelf life or they can be byproducts of the paint drying process. Currently, high quality, "low VOC" paint and coating products with desired performance characteristics are available for use in school environments. These types of paint and coating products minimize indoor air pollution loads and reduce health risks to both workers and occupants.

School Demonstration Studies. In the fall of 2011, UL-GREENGUARD conducted two demonstration studies at a public middle school in Savannah, Georgia, to evaluate the impact that different types of paints have on IAQ in educational environments. The studies were a collaborative effort among UL's GREENGUARD Environmental Institute, Sherwin-Williams, the Georgia chapter of the U.S. Green Building Council, and the Chatham County (Georgia) School District. The primary objective of the first school demonstration study was to compare airborne levels of VOCs when a

conventional semi-gloss paint was used on interior wall surfaces versus a formulation of low VOC semi-gloss paint (VOC ≤ 50 g/L). In this first study, two separate classrooms were chosen to be painted, one with a conventional semi-gloss paint and one with a GREENGUARD certified low VOC semi-gloss interior paint satisfying the GREENGUARD Children and Schools chemical emission standards, including the California 1350 individual chemical requirements for chronic reference exposure levels (GEI-GGPS.002, 2011 and CDPH, 2010).

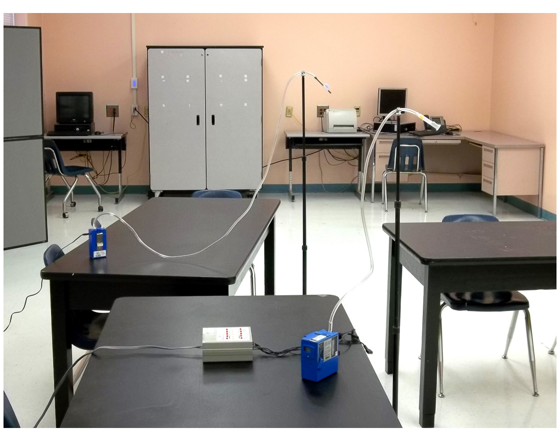
Paint was applied to each room by the school's maintenance staff using standard practices. Paint was applied to the walls with rollers, and brushes were used to paint trim, edges and other finishing requirements. Each room was painted at a unique time, and care taken to ensure that ventilation systems among rooms were separate and did not introduce cross contamination. VOC testing of each room was conducted prior to the paint being applied and immediately following complete application. Periodic monitoring extended for 14 days following the initial paint application.

Prior to application of these two paints in the school, laboratory emission profiles were determined for each paint using small environmental chambers following standard test and measurement protocols (ASTM D 5116, 2009 and GEI, GGTM.P066, 2011). Each paint was evaluated for the identification and quantitation of VOCs, extending out to 14 days. Each of the paints contained the same quantum of tint as to be applied in the school.

In addition, a second school demonstration study was also conducted to evaluate the effectiveness of a new paint specifically formulated to reduce airborne concentrations of formaldehyde and other aldehydes. This new paint, Sherwin-Williams enhanced Harmony® Paint, was also used to paint a comparative classroom. The measured IAQ in this classroom was then compared to that of the other classrooms painted with the conventional semi-gloss paint and the low VOC semi-gloss paint.

2 MATERIALS / METHODS

Monitoring of VOCs*.* Airborne VOC samples were evaluated using gas chromatography with mass spectrometric detection ("GC/MS"). Chamber air was collected onto a sorbent tube which was thermally desorbed into the GC/MS. The sorbent collection, separation, and detection methodology had been adapted from techniques presented by the USEPA and other researchers. The technique followed standard measurement methods (USEPA Method IP-1B, 1999 and ASTM D 6196, 2009) that are generally applicable to C6 - C16 organic chemicals with boiling points ranging from 35ºC to 250ºC. Measurements were reported to a quantifiable level of 1 μg/m³. A total VOC ("TVOC") measurement was made by adding all individual VOC responses obtained by the mass spectrometer and calibrating the total mass relative to toluene. Individual VOCs were quantified to authentic standards if available; others were calibrated as toluene equivalents.



Product Testing and Verification. All paint products applied in the first school demonstration study were chamber tested according to the GREENGUARD "Standard Method for Measuring and Evaluating Building Materials, Finishes, and Furnishings Using Dynamic Environmental Chambers" (GEI, GGTM.P066, 2011), as well as standard guidance for VOC measurements using environmental chambers (ASTM D5116, 2010). The paints were applied to a standard wall substrate and emissions of VOCs were measured and identified. Data from the emissions tests were used to track VOCs found in the freshly painted classrooms.

3 RESULTS / DISCUSSION

Environmental Chamber Emission Studies. Table 1 presents the TVOC levels measured from the conventional semi-gloss paint and the low VOC semi-gloss paint over a 14-day study period. The two paints remained in the environmental chamber during the complete study. In addition, the primary VOCs found emitting from each paint are presented in Table 2.

Table 1. Chamber Emission Profiles TVOC

MEASURED TIME POINT (hr)	CONVENTIONAL PAINT EMISSION FACTOR (µg/m²•hr)	LOW VOC PAINT EMISSION FACTOR (µg/m²•hr)
6	2172	286
24	502	32
48	272	7.7
72	155	2.1
96	127	2.0
168	90	---
336	51	---

Table 2. Primary VOCs Measured from Paint Emission (Highest Emitting)

CONVENTIONAL PAINT		LOW VOC PAINT	
ANALYTE	EMISSION FACTORS (µg/m²•hr)	ANALYTE	EMISSION FACTORS (µg/m²•hr)
1-Hexanol, 2-ethyl	476	Undecane	29
Cyclotetrasiloxane, octamethyl	449	Ethylene glycol	23
2-Propenoic acid, 2-methyl-, butyl ester (Butyl methacrylate)	206	n-Butyl ether	22
Acetic acid, 2-ethylhexyl ester	152	1,2-Propanediol (Propylene glycol)	18
1-Butanol (N-Butyl alcohol)	134	Dipropylene glycol	17
1-Hexanol (N-Hexyl alcohol)	95	Dodecane	13
Ethanol, 2-(2-butoxyethoxy)	79	1-Propanol, 2,2'-oxybis-	11
Chloroacetic acid, 2-ethylhexyl ester	58	1-Propanol, 3,3'-oxybis-	9
Benzene, ethyl	49	Cyclohexane, 1-ethyl-2-propyl	9
Xylenes	31	Cyclohexanone, 3-butyl-	9

Classroom VOC Field Studies. Airborne VOC levels in each classroom painted with the semi-gloss conventional and low VOC formulations were studied over a 14-day period following application of the paints. Initial measurements were made one hour following paint application. The primary VOCs (top 6) of each paint, as identified in the chamber emission studies, were individually tracked over time. The results for the conventional semi-gloss paint and the low VOC semi-gloss paint are presented below in Tables 3 and 4, respectively. While this first study was taking place, VOCs were also measured in the classroom painted with Sherwin-Williams enhanced Harmony® Paint for comparison purposes. Results with respect to enhanced Harmony® Paint are shown in Table 5.

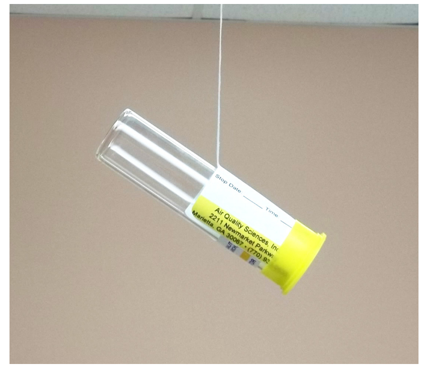


Table 3. Primary Paint VOCs Measured in Classroom after Painting Conventional Semi-Gloss Paint Concentrations (µg/m³)

ANALYTE	TIME AFTER PAINTING			
	1 HR	24 HR	7 DAYS	14 DAYS
Cyclopentasiloxane, decamethyl	380	121	26	16
Acetic acid, 2-ethylhexyl ester	250	35	18	12
1-Hexanol, 2-ethyl	230	35	8	3
2-Propenoic acid, 2-methyl-, butyl ester (Butyl methacrylate)	212	32	nd	nd
Cyclotetrasiloxane, octamethyl	190	61	15	8

nd - not detected

Table 4. Primary Paint VOCs Measured in Classroom after Painting Low VOC Semi-Gloss Paint Concentrations (µg/m³)

ANALYTE	TIME AFTER PAINTING			
	1 HR	24 HR	7 DAYS	14 DAYS
1,2-Propanediol (Propylene glycol)	19	2	nd	nd
Dipropylene glycol	14	3	nd	nd
n-Butyl ether	13	nd	nd	nd
Undecane	7	nd	nd	nd
1-Propanol, 2, (2-hydroxypropoxy)	4	nd	nd	nd

nd - not detected

Table 5. Primary Paint VOCs Measured in Classroom after Painting Enhanced Harmony® PaintConcentrations (µg/m³)

ANALYTE	TIME AFTER PAINTING			
	1 HR	24 HR	7 DAYS	14 DAYS
n-Butyl ether	11	nd	nd	nd
Butyl propionate	6	nd	nd	nd
1-Butanol	4	nd	nd	nd
Butylacetate	2	nd	nd	nd

nd - not detected

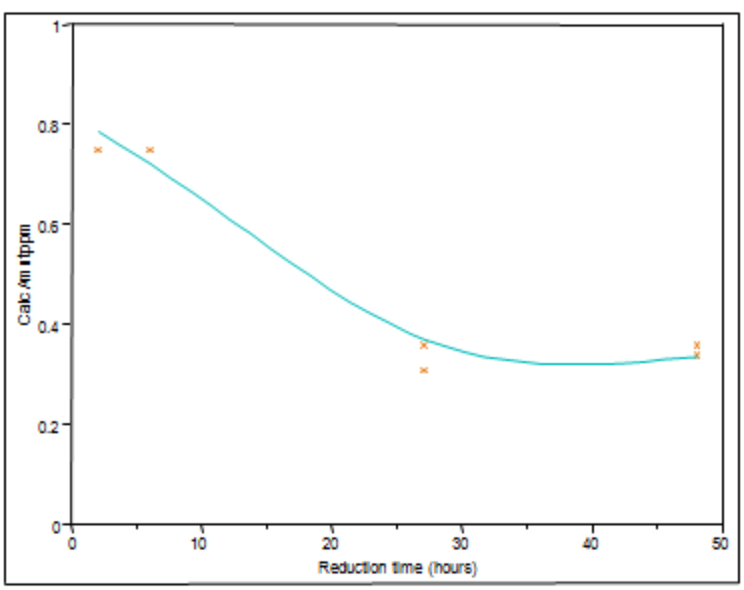
Conventional Semi-Gloss Paint vs. Low VOC Semi-Gloss Paint Emission Study. Environmental chamber studies showed a significant difference in total VOC emissions between the conventional and low VOC semi-gloss paints studied and the length of time emissions were detected. The conventional semi-gloss paint showed initial TVOC levels approximately 8 times higher than the low VOC semi-gloss paint, with both exhibiting decreasing emissions over time. The low VOC semi-gloss paint reached non-detectable levels within 7 days and the conventional semi-gloss paint within 14 days. Individual VOCs varied among the two paints. Primary emissions of the conventional semi-gloss paint included various siloxanes, acrylates, alcohols and aromatic solvents, and the low VOC semi-gloss paint demonstrated emissions of glycols, other alcohols and numerous alkanes. Individual VOCs associated with the conventional semi-gloss paint were typically found at levels 10 times the magnitude of those measured in the low VOC semi-gloss paint.

Laboratory VOC Reduction Study - Formaldehyde Reduction Measure

External Laboratory Methodology. Data was obtained from dried paint films placed into inert chambers that were subsequently spiked with formaldehyde. The 7 mil (wet) paint films were prepared on aluminum panels and dried for 3 days under "clean air" conditions of 75°F and 50% relative humidity. These paint panels were placed into Tedlar™ bags (10 liter) and 1% formaldehyde solution in water was injected into each bag to yield the appropriate equivalent air concentration (1, 10 or 100 ppm). At various time intervals, the formaldehyde present in each bag was measured with direct injection GC/MS or high performance liquid chromatography ("HPLC") via derivatization in accordance with ISO-16000-3. Data for external calibration standards and the baseline for empty bags were measured with each series and used to determine actual formaldehyde levels and % reduction.

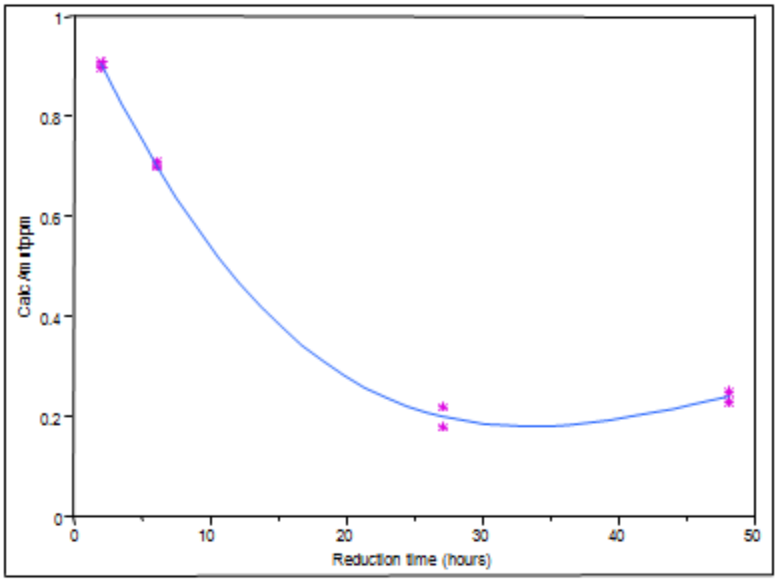
The rate of formaldehyde reduction shown in the following 3 figures was measured by spiking the static bag with 1 ppm formaldehyde and then measuring the level over the next 2 days. There is significant reduction of formaldehyde in the empty bag at this low concentration

Figure 1. Rate of formaldehyde reduction in an empty bag (calculated ppm)



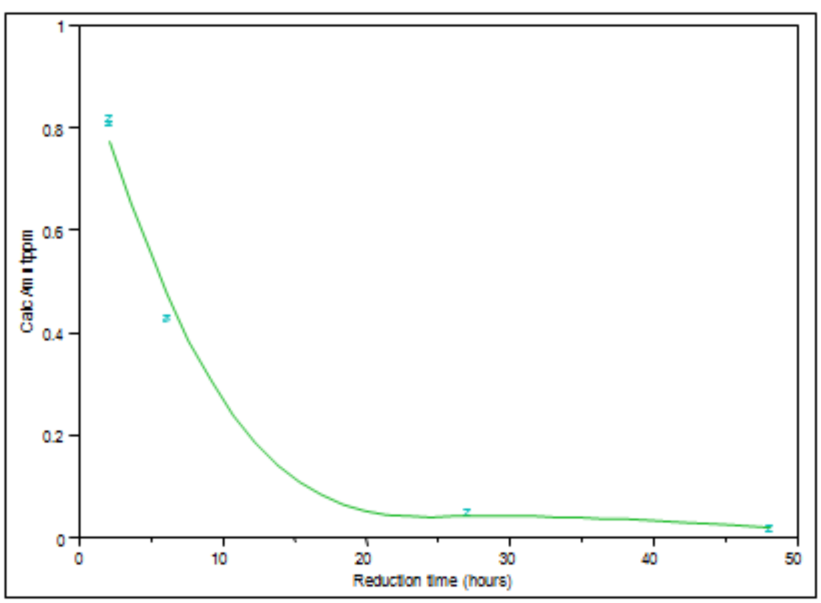
A conventional paint, used as the control, lowers the level of formaldehyde in the chamber, but there is a slow release back to the environment over time as shown in Figure 2.

Figure 2. Rate of formaldehyde reduction in the presence of conventional paint (calculated ppm)



As indicated below in Figure 3, Sherwin-Williams enhanced Harmony® Paint reduces the level of formaldehyde more quickly than conventional paint and to lower levels. In addition, enhanced Harmony® Paint does not release the formaldehyde over time as was seen with the conventional paint.

Figure 3. Rate of formaldehyde reduction in the presence of enhanced Harmony® Paint (calculated ppm)



Studies were completed to determine if the reaction between formaldehyde and Sherwin-Williams enhanced Harmony® Paint was reversible. This test was completed using 100 ppm of formaldehyde in a Tedlar™ bag. After 6 days of equilibration, the bag was purged, refilled with clean air, allowed to re-equilibrate for 3 days and then the level of formaldehyde was measured. This process was repeated to determine if formaldehyde would be released from enhanced Harmony® Paint. The amount released was then compared to the amount released by an empty bag or the conventional paint.

The results show that Sherwin-Williams enhanced Harmony® Paint reduces the level of formaldehyde in the bag significantly more than the conventional paint. A slight amount of formaldehyde is lost to the surface of the empty chamber. The enhanced Harmony® Paint absorbs nearly 4 times more formaldehyde than the conventional control paint as shown in Figure 4.

Figure 4. Formaldehyde reduction (%)

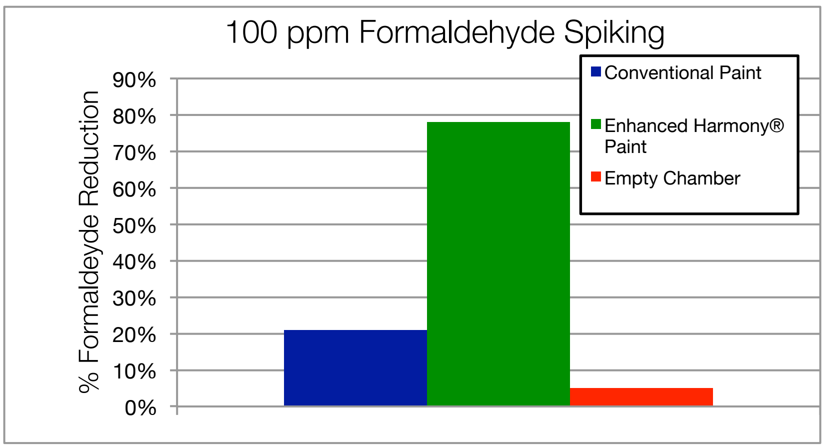
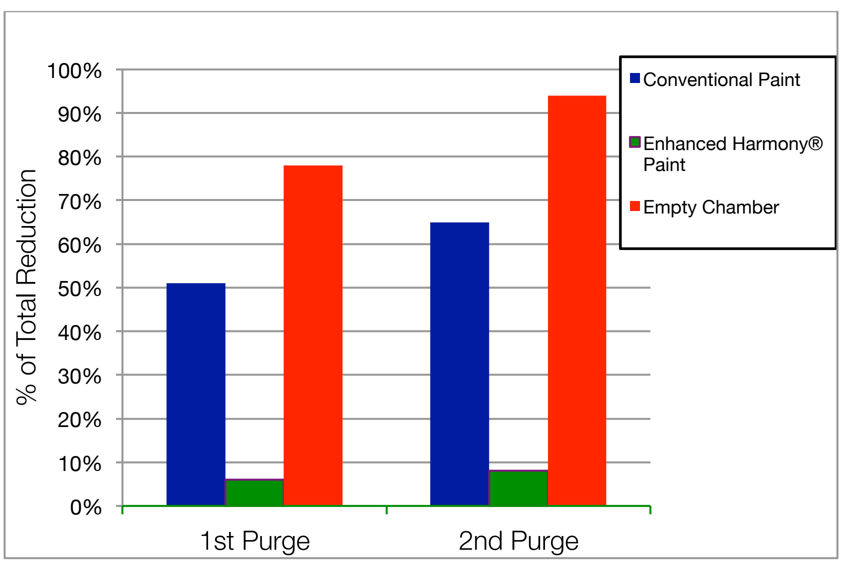


Figure 5. Formaldehyde released (%)



The actual data from the reversibility study is shown in ppm in Table 6.

Table 6. Formaldehyde released after purging with clean air (ppm)

100ppm to Start	PPM Formaldehyde Remaining	1st Purge then 3-Day Equilibrate	2nd Purge then 3-Day Equilibrate
Conventional Paint	79	10.7	3.2
Enhanced Harmony® Paint	22	4.9	1.7
Empty Chamber	94	4.7	1.0

Blind validation testing was completed on samples using 10 ppm formaldehyde in a Tedlar™ Bag and allowing it to equilibrate for 3 days. Results are shown in Table 7. Similar results were obtained with tinted versus untinted samples. Overall, testing confirmed that enhanced Harmony® Paint was effective in reducing formaldehyde at levels varying from 1 to 100 ppm.

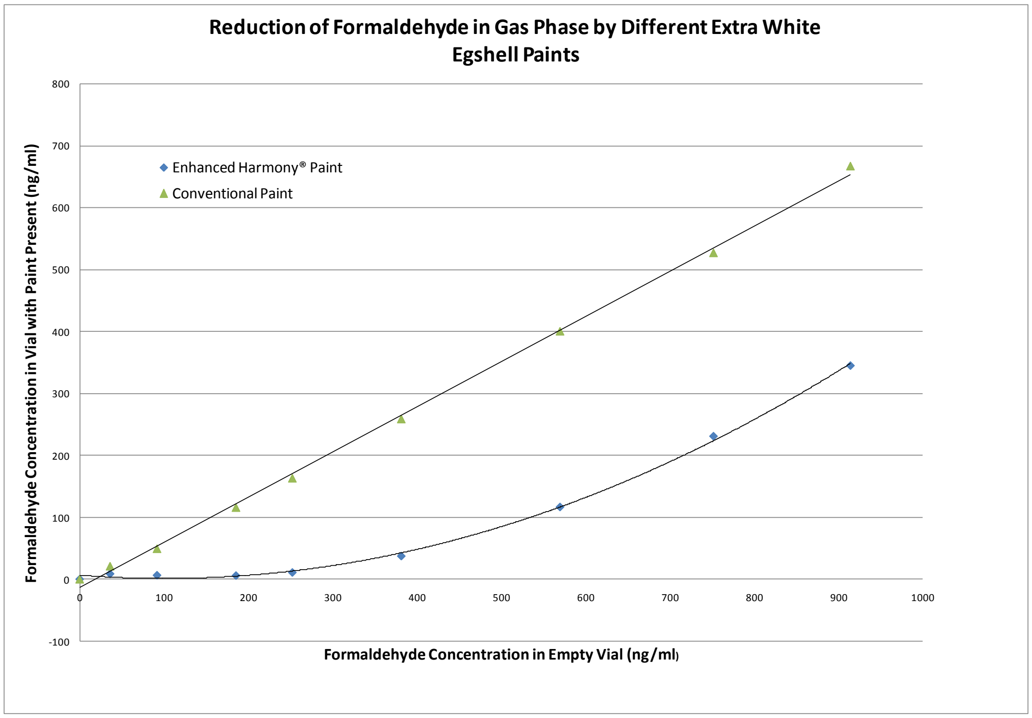
Table 7. Blind Validation Testing at 10 ppm Formaldehyde over 3 Days

Paint Description	Formaldehyde Reduction
Enhanced Harmony® Paint	
Batch – Untinted	100%
Batch – Tinted	100%
Conventional (Control) Paint	44%

Alternate Methodology. This technique is similar to the external methodology, but involves the exposure of a cured paint film (48 hours dry at room temperature and humidity and cut to 1/4 inch diameter circle) to known concentrations of formaldehyde in sealed vials. The vials are left to equilibrate in an environmental chamber at 23°C for 24 hours. The measurement of formaldehyde remaining in the vapor phase after exposure is completed by sweeping the headspace onto a formaldehyde absorbing cartridge for subsequent HPLC analysis.

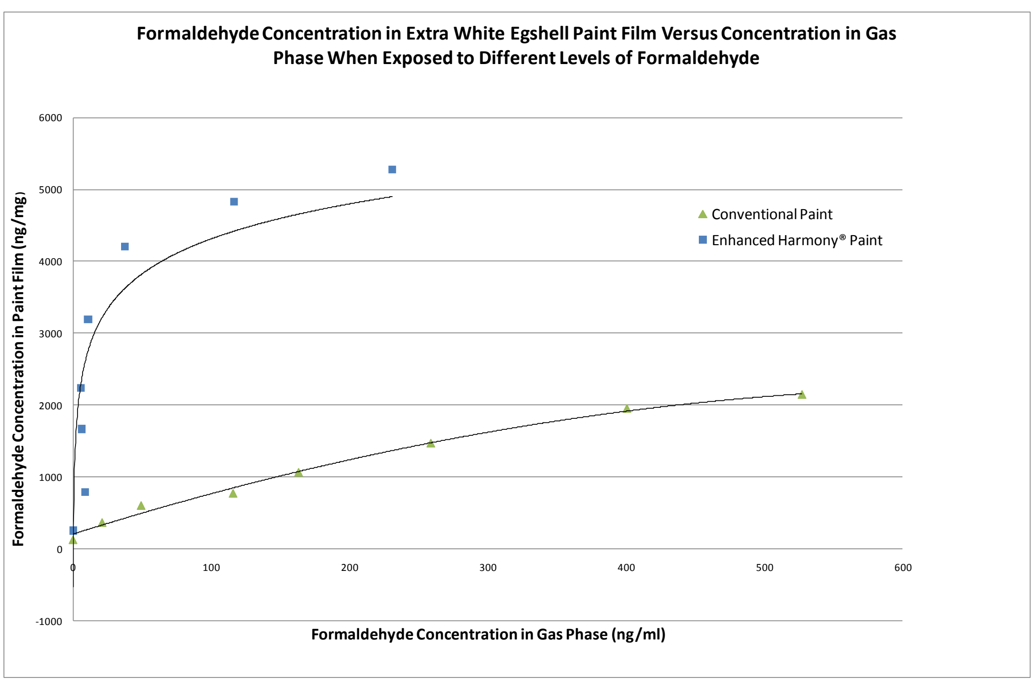
Figure 6 shows the amount of formaldehyde remaining in the gas phase after exposure to paint films. Each point of the graph is a separate vial exposed to increasingly higher levels of formaldehyde. At the lower levels, the total amount of formaldehyde added is completely consumed by the small volume of enhanced Harmony® Paint, up to 200 ng/ml or approximately 150 ppm. Even when exposed to high levels of formaldehyde, the enhanced Harmony® Paint consumes significantly more formaldehyde than a conventional paint.

Figure 6. Reduction of formaldehyde (ng/ml)



Another way to look at the data is shown in Figure 7. This graph shows the calculated amount of formaldehyde consumed by the paint film. Each point is a separate test at increasingly higher initial levels of formaldehyde. Enhanced Harmony® Paint continues to consume formaldehyde up to 2000 ng/mg until the paint reaches saturation and then the formaldehyde starts to build up in the vapor phase.

Figure 7. Calculated amount of formaldehyde reduction (ng/ml)



Dynamic Chamber Studies of Formaldehyde Reduction. Formaldehyde reduction studies were conducted by challenging both a low VOC paint (the control paint) and Sherwin-Williams enhanced Harmony® Paint with dynamic air containing known concentrations of formaldehyde. Paint samples applied to wall board were prepared for the VOC emission chamber studies. These samples were placed in dynamic environmental chambers, and supplied with air containing known concentrations of formaldehyde. Constant formaldehyde concentrations were achieved with calibrated permeation tubes and maintained over a 7-day period for each of the chamber studies. Periodic air data was obtained across the 7-day period, and reduction measures were made by comparing the formaldehyde level in the chamber before and after introduction of the paint product. Net formaldehyde reduction was the difference from that obtained for the control paint and the enhanced Harmony® Paint containing the formaldehyde reducing technology. Reduction was studied for a low and high concentration of airborne formaldehyde, 60 ug/m^3 and 500 ug/m^3, respectively. The 60 ug/m^3 (49 parts per billion or 49 ppb) value represents a typical indoor environment. Results as demonstrated in Table 8 indicate a measurable formaldehyde reduction with the enhanced Harmony® Paint in comparison to the control low VOC paint at formaldehyde concentrations, averaging 15.7 % for 60 ug/m^3 and 19.1% for 500 ug/m^3. Reduction levels appear to equilibrate within 48 hours of formaldehyde exposure and hold constant throughout the 7-day test period as demonstrated in Figure 8.

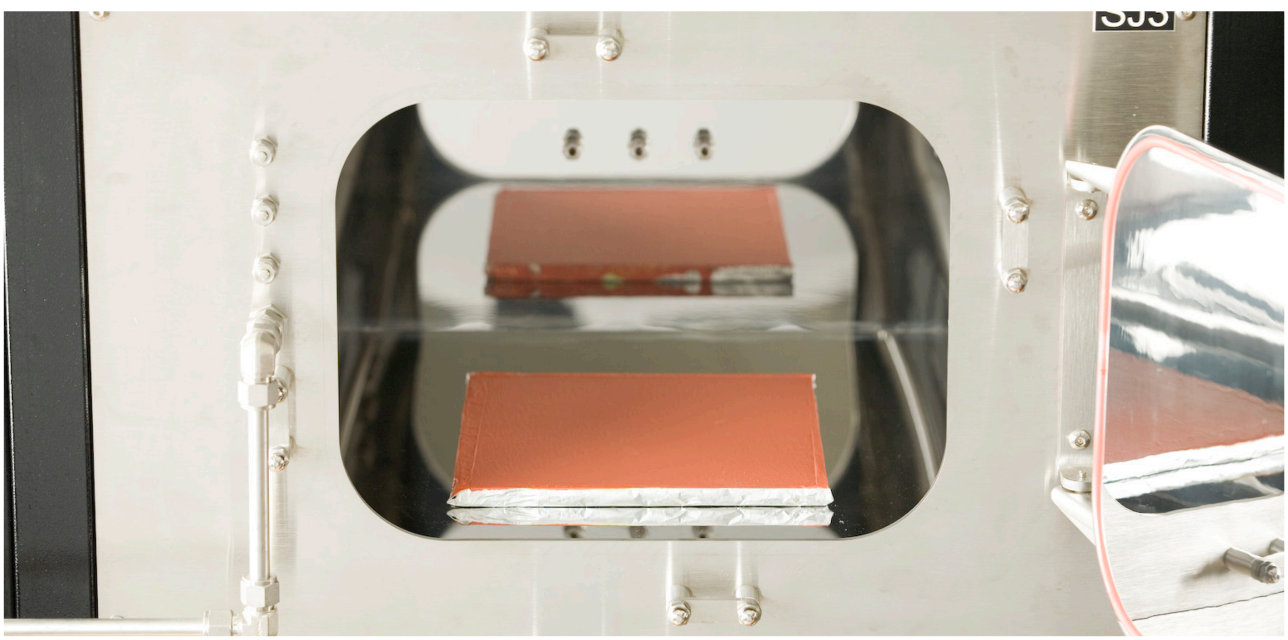
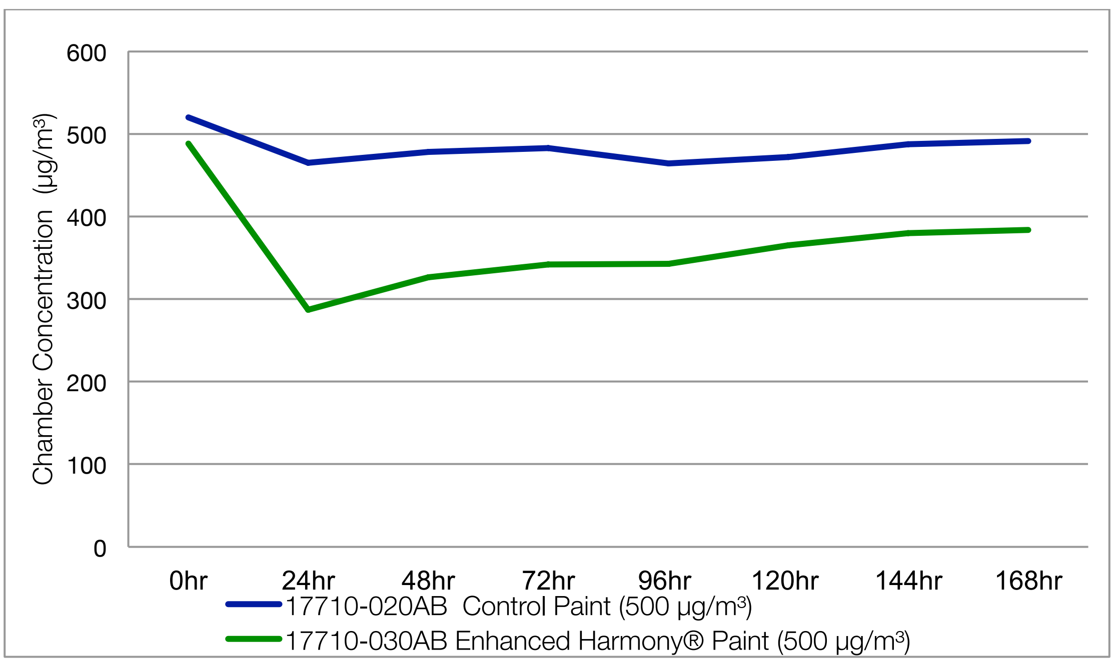


Table 8. Formaldehyde reduction for control paint and enhanced Harmony® Paint at two target concentrations

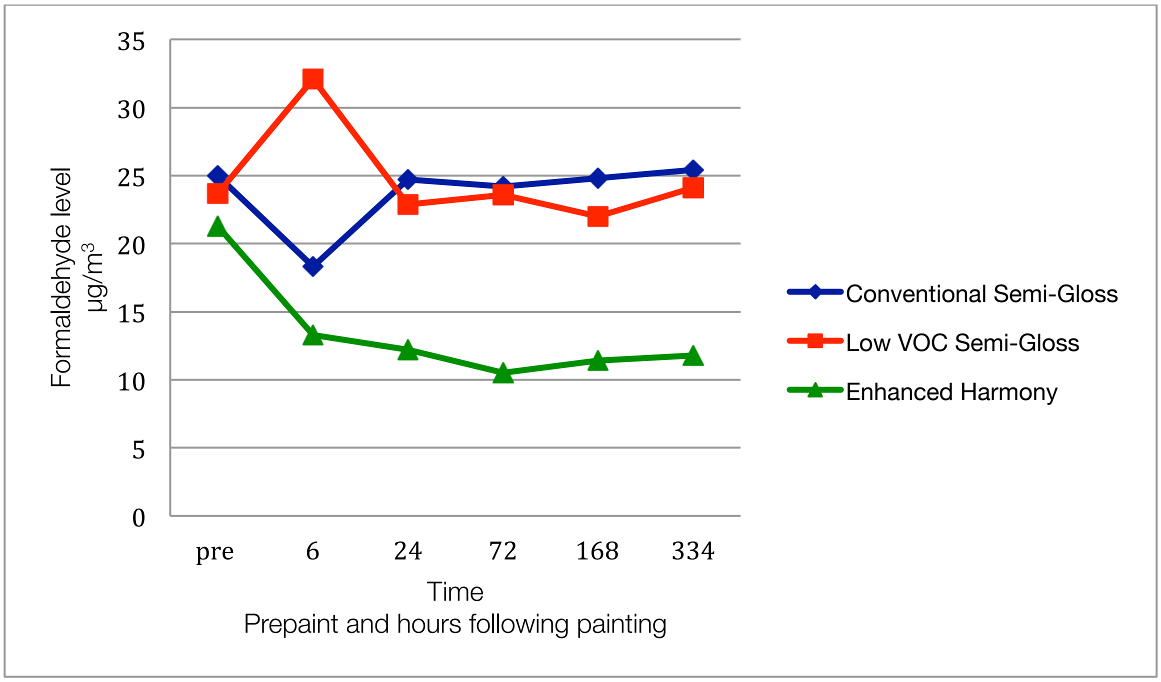
Target Inlet Concentration	Percent Formaldehyde Reduction Following Air Exposure
60 µg/m³	
Control Paint	9.4%
Enhanced Harmony® Paint	25.1%
Net Reduction	15.7%
500 µg/m³	
Control Paint	7.8%
Enhanced Harmony® Paint	26.9%
Net Reduction	19.1%

Figure 8. 500 µg/m³ Formaldehyde Target Challenge



VOC Reduction in the Classroom. Measured VOCs in the classrooms painted with the conventional semi-gloss and low VOC semi-gloss paints were compared to those found in the classroom painted with Sherwin-Williams enhanced Harmony® Paint. Measurements were made prior to painting and up to 336 hours following painting. The data showed a meaningful reduction of airborne formaldehyde, as demonstrated in Figure 9, for the classroom painted with enhanced Harmony® Paint.

Figure 9. Formaldehyde comparison across classrooms following application of various paints (µg/m^3)



4 CONCLUSIONS

The first school demonstration study showed that the low VOC semi-gloss paint contributed lower levels of VOCs to the air when compared to the conventional semi-gloss paint previously used by the school. The low VOC paint's highest contribution to the classroom air was propylene glycol at 19 ug/m^3. All other contributing VOCs were lower in concentration. In addition, all individual VOCs were less than 5 ug/m^3 within 24 hours after paint application, and there were no detectable paint emissions 7 days after application. In contrast, the conventional paint showed VOC contribution greater than 100 ug/m^3 for numerous VOCs, and some of these VOCs were still present in the classroom 14 days after paint application. Total VOC load and relative levels of VOCs can be an indicator of expected human comfort and acceptance of the air quality. Consequently, expectations of higher quality indoor air with lower chemical exposure and greater human comfort would be expected with use of a low VOC paint.

Various laboratory methods confirm that Sherwin-Williams enhanced Harmony® Paint with formaldehyde reducing technology can reduce the amount of formaldehyde from the gaseous phase near the paint. This was validated in the second school demonstration study conducted by UL-GREENGUARD. The second school demonstration study showed that airborne formaldehyde levels were significantly reduced in the classroom through use of enhanced Harmony® Paint. The average 5-day airborne levels for each classroom prior to painting were compared to the 7-day (168 hour) average level after painting. There was a 45% reduction in airborne formaldehyde in the room painted with enhanced Harmony® Paint. In contrast, there was no reduction of formaldehyde level in the room painted with the conventional semi-gloss paint and a 9% reduction in the room painted with the low VOC semi-gloss paint. The 9% reduction was not significant since it was within the typical room formaldehyde concentration variation of 12%.

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