contaminants in from the garage and transport them to the living space.

"This is not the ASHRAE standard to deal with CO," Lstiburek explained. "This is the ASHRAE standard for acceptable indoor air quality. I've tested houses and found a 150 cfm return from garages.... I can show you that when the air handler in the garage operates, you pull air from the garage into the house. If I had my druthers, I wouldn't put the air handler and ductwork in the garage."

Hosler responded, "Of all the installations we have, our tests show no problems."

"It depends on what you're testing for," Lstiburek replied. "You're testing for CO, and it's not showing up. We're talking about all volatile organic compounds [from household hazardous materials people generally store in garages]. Is it prudent to move air from the garage into the house? My experience is no — it is a bad idea."

Referring to the requirement for a mechanism to automatically close the door between the garage and living space, Richardson said that during an "informal survey," he had not found anyone in Tuscaloosa who wanted it. Hedrick replied that New Mexico has required the automatic door closers for years.

Among other comments, an audience member pointed out that Standard 62.2P refers to numerous standards by governmental and other organizations that those organizations may change. Sherman replied that Standard 62.2P would be on "continuous maintenance," which is the process ASHRAE committees use to continually review and revise standards as circumstances warrant.

PRACTICAL RESEARCH BRIEFS

What Impacts Do Combinations of Building Materials and Intermittent Ventilation Have on Perceived Indoor Air Quality?

Indoor air quality (IAQ) experts know that many building materials and consumer products are significant sources of indoor air pollution. Many have believed that ventilation is the best strategy for improving IAQ, but no systematic study had yet shown how effective this strategy is or when it is impractical.

Furthermore, ventilation rates for offices, schools, and other nonindustrial buildings are largely set according to the number of occupants irrespective of other sources of indoor pollutants. (Pollutants from a variety of sources are recognized in the American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] Standard 62-1999, which requires that those responsible should factor in emissions from building materials and equipment as well as the number of occupants to establish the ventilation rate for acceptable IAQ.)

In addition, in buildings where the ventilation rate is reduced at night to conserve energy, daytime air quality may worsen due to a buildup of contaminants overnight and to the sorption process, which releases pollutants during the day that are absorbed by interior surfaces overnight.

Temperature, relative humidity, air velocity, ventilation rate, surface treatments, age of materials, and pollution from other sources absorbed on those materials alter emission rates. Researchers who have established the exposure-response curve for eight common materials generally concluded that source control is often the best way to improve IAQ. While other studies determined that intermittent ventilation (i.e., night setback) diminishes daytime IAQ, those studies ignored the interaction between the different materials used to construct and furnish a building.

Fariborz Haghighat, Wafa Sakr, Lars Gunnarsen, and Michael Von Grunau performed a series of experiments in test chambers and in three buildings to determine the impact of ventilation system practices and varying combinations of building materials on how people perceive air quality. Their research is published in *ASHRAE Transactions 2001*, Volume 107, Part 1.

Haghighat is a professor and Sakr is a research assistant for the Department of Building, Civil and Environmental Engineering at Concordia University in Montreal, Quebec, Canada.

Gunnarsen is a senior researcher at the Danish Building Research Institute in Hørsholm, Denmark. Von Grunau is a professor for the Department of Psychology at Concordia University. The Concordia University Faculty Research Development Program and NATO's Scientific Affairs Division funded their experiments.

"The exposure-response relationships make it possible to systematically quantify and assess the impact of emissions from building materials on perceived air quality at different concentrations," the researchers note. Using the exposure-response curve, they determined the increases in ventilation rate required to maintain a certain level of acceptability of indoor air.

Methodology: Test Chambers

In the lab, Haghighat, Sakr, Gunnarsen, and Von Grunau used three steel test chambers with glass lids. The chamber interiors were electroplated with chrome to reduce adsorption and desorption. Before each experiment, the researchers thoroughly cleaned each chamber and calibrated them to ensure each had the same amount of supply air — approximately 0.9 liters per second — and velocity near the sources. They then covered the chambers with aluminum foil so the panelists assessing air quality could not see the materials being tested. They diluted polluted exhaust air at different rates by mixing test chamber air with different amounts of supply air.

The researchers tested five building materials: two types of carpet, vinyl (PVC) flooring, and two types of waterborne wall paint. All the materials were new. Several days before each experiment, the flooring samples were stapled back-to-back to prevent emissions from their backs. Test materials were sized so that each sample corresponded to a model room with a volume of 17 cubic meters (m^3), or 3.2 x 2.2 x 2.4 meters.

For Tests 1 and 2, the experiments considered 100% of the "model room walls" painted and 100% of the "floor" covered by carpet or PVC. For Tests 1, 2, and 3, they assumed an air exchange rate of 2 per hour. In Tests 4 and 5, they used an air exchange rate of 4 per hour. For additional insight, they also had the panelists assess the quality of supply air.

In Test 1, the researchers wanted to have the panel assess to what degree indoor air is acceptable when there is continuous ventilation. They ventilated the specimen building materials in the test chambers continuously for six days. On the sixth day, 50 panelists assessed the immediate acceptability of the air.

In Test 2, panelists assessed the acceptability of indoor air when ventilation is intermittent. Chambers were ventilated for 12 hours, followed by no ventilation for 12 hours on each of six days. While the ventilation fan in each chamber was off, the ventilation rate was nearly two orders of magnitude less than when it was on. On the sixth day, after a fan had been operating for 4-6 hours, 42 panelists assessed the acceptability and the odor intensity of the exhaust air.

In Test 3, researchers wanted to determine the exposure-response relationship of each building material. They placed one material in each test chamber for three days before 29 panelists assessed the air quality for acceptability and odor intensity at five different concentrations.

In Test 4, researchers placed one material in each chamber with almost the same airflow rate, but the materials were only about half the size of the samples in the earlier tests. After six days, 39 panelists assessed the chambers' air quality for acceptability and odor intensity at five different concentrations.

Finally, in Test 5, they placed half-sized combinations of two materials (either both paint and carpet, paint and PVC, or PVC and carpet) into the test chambers for six days. Then 34 panelists assessed the air quality from the chambers for acceptability and odor intensity. Researchers conducted five rounds of sensory testing, and randomly varied the dilution each round and between test chambers.

Methodology: Office Buildings

For their field experiments, the researchers chose three office buildings with mechanical systems that could ventilate with almost 100% outdoor air. Panelists assessed the air quality in each building when the heating, ventilation, and air conditioning (HVAC) system was operating continuously and also when it was operating intermittently for 12 hours on and 12 hours off.

During Round 1, 35 panelists assessed the air quality in two buildings after the ventilation had run continuously for six days, and in the third building after ventilation had run intermittently for six days. In Round 2, ventilation strategies were switched for six days before 35 panelists assessed air quality. In both experiments, panelists evaluated the acceptability and odor intensity of the air immediately after entering each test room. Assessments were made at mid-morning before building occupants arrived. In cases where the HVAC operated intermittently, the assessments started 4-5 hours after mechanical ventilation had resumed.

Haghighat, Sakr, Gunnarsen, and Von Grunau used tracer gas to measure the air exchange rate and a balometer to measure the supply and return airflow rate. They maintained temperature at 21°C ± 1°C and relative humidity (RH) at 35% ± 5% RH. "It is important to note," they emphasize, "that differences between ventilation rates in the 'on' and 'off' [intermittent versus constant ventilation] situations are far smaller than during chamber tests."

Methodology: Sensory Panel

In both the test chamber and office building experiments, the panelists were volunteer university students aged 21 to 43, with an average age of 32. Some 72% were men and 21% were smokers. Panels included 29 to 50 people. Panelists made their immediate assessments of air from test chamber diffusers and in the office buildings by marking an acceptability scale, which ranged from "clearly acceptable" (a rating of +10) to "clearly not acceptable" (a rating of -10). Researchers had labeled the midpoint 0. The panelists also rated air odor intensity compared to outdoor air, which the researchers had assigned an odor intensity of 10.

For the laboratory experiments, the researchers told the panelists to consider the odor intensity of the lab room air as 10. They should assess exhaust air from each test chamber at more than 10 if its odor seemed stronger, or less than 10 if it seemed weaker. They must also wait at least three minutes after each assessment before assessing the next chamber's exhaust.

Before the experiments, the researchers "carefully instructed" panelists on how to use the scales, pointed out that their focus should be on the initial perception, and stressed that no panelist should communicate his or her perception of air quality during the experiments.

Results

For Test 1 with continuous ventilation, panelists gave paint their highest average acceptability rating, +1.6. They gave the carpet-exhaust air an average –0.6 acceptability rating and the PVC-exhaust air an average rating of –4.7.

In Test 2 with intermittent ventilation, panelists gave paint an average acceptability vote of –0.27, gave carpet an average of –2.6, and ranked PVC-exhaust air acceptability at –5.7 (see Figure 1 for results from Tests 1 and 2).

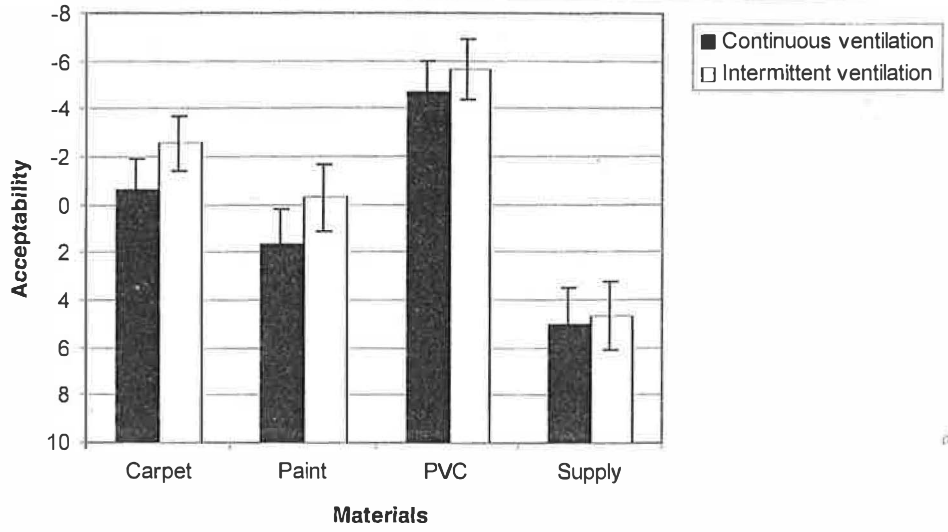
In Test 3 of individual building materials, the perceived air quality improved for all materials when the researchers increased the dilution air in the chambers. Diluting the PVC-exhaust air produced the greatest improvement. "When the polluted [PVC] air was diluted 16 times, the acceptability increased from –4.63 to +2.56, while for the paint, the 16-fold dilution increased the acceptability from +0.04 to +2.43," researchers say.

The 16-fold dilution increased the acceptability of the carpet-polluted air from –1.47 to +3.02. "A strong improvement occurred when the polluted air was diluted between 1 and 6 times, while just a small improvement occurred between 6-fold and 16-fold dilution."

For all tested materials, the 16-fold dilution produced an acceptability rating of about +3. Even at 16-fold dilution, however, panelists could distinguish between the test chambers where building materials were present and those where the test chambers contained only supply air.

Results of Test 4 allow comparisons between the tested materials at different dilutions (see Figure 2). At the most concentrated pollution level, paint had the highest average acceptability at –1, with PVC acceptability at –1.4 and carpet acceptability at –3. The researchers surmise that the difference between these results and those in the experiment on ventilation strategies could be because the materials used in Test 4 differed from those in the previous experiments.

Figure 1



Laboratory measurements: mean acceptability and odor intensity votes at continuous and intermittent ventilation.

Test 5 showed the exposure-response relationship between the dilution factor and the mean acceptability for combinations of carpet and paint, paint and PVC, and carpet and PVC. "The results [we] obtained for the various combinations of materials provide a linear relationship with good regression coefficients," the researchers report. "At the highest concentration, the mean acceptability vote was –2.27 for carpet and PVC, –1.66 for paint and carpet, and –0.84 for paint and PVC." At a 6-fold dilution of the polluted air, the combination of carpet and PVC produced an acceptability mean almost as good as the supply air — the most pronounced improvement among the three combinations.

Discussion

The intermittent ventilation strategy is widely used in office buildings to reduce energy costs. The researchers' results show how this strategy of shutting off ventilation at night negatively impacts perceived IAQ. Indoor air pollution levels rise at night when mechanical ventilation is off, the researchers observe, causing indoor surfaces to absorb pollutants. Desorption of such pollutants can occur when air pollution levels decline after mechanical ventilation resumes. The difference in partial pressure between material and air drives this desorption to the air, they say, and in fact, their results agree with those from other studies.

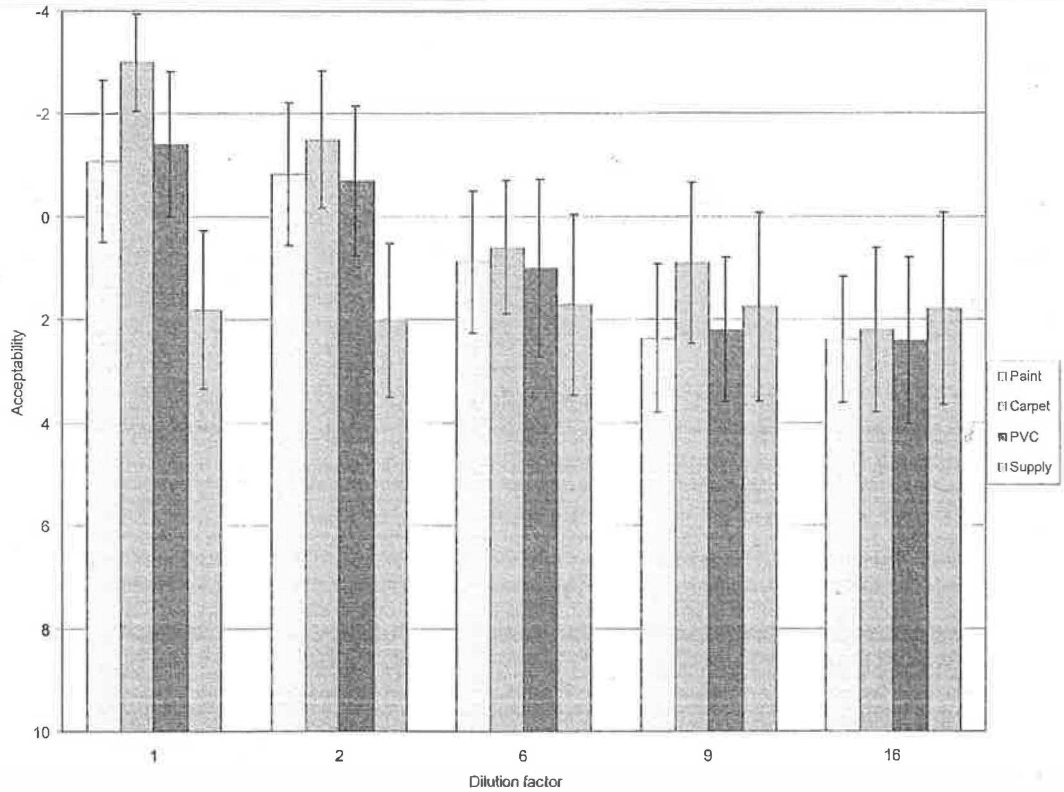
"These studies show that the sorption behavior has to be included when estimating the variation in concentration in a room based on source characteristics and ventilation rates," the researchers conclude. Their results show that when ventilation is used intermittently, office buildings need far more ventilation during the day to maintain IAQ that is as acceptable as that in buildings with continuous ventilation.

"The ratios between these dilutions have an average of 3.8," the researchers note. "This means that when intermittent ventilation is applied, the materials require, on average, a 3.8-times higher ventilation rate than [in buildings] with continuous ventilation." In short, they say, buildings that ventilate intermittently require a bigger mechanical system "to provide 3.8-times higher average ventilation rate over 24 hours during [the hours of mechanical ventilation, which results in] higher energy cost and higher initial cost."

Even so, the findings show that a given ventilation strategy had a less significant effect in the field test results than in the chamber test results. Moreover, air acceptability for the individual materials in the lab experiments was significantly less than assessed for the three test offices. Haghighat, Sakr, Gunnarsen, and Von Grunau suggest several possible reasons for these discrepancies:

1. One test showed that perceived air quality might improve by combining sample building materials. Since the building has multiple materials, one would expect it to produce a flatter

Figure 2



Mean acceptability vote for single materials at different dilutions.

exposure-response curve than the curves for one or two materials did.

2. The tested offices were more than 30 years old, and the contribution of odor from construction materials was limited. Newer materials have higher pollution-emission levels.

3. The offices had a higher number of air changes per hour (ach) when the ventilation system stopped (ach = 1), largely due to infiltration. With no mechanical ventilation, the test chambers had an ach of nearly zero.

4. Other factors that may have had an impact include:

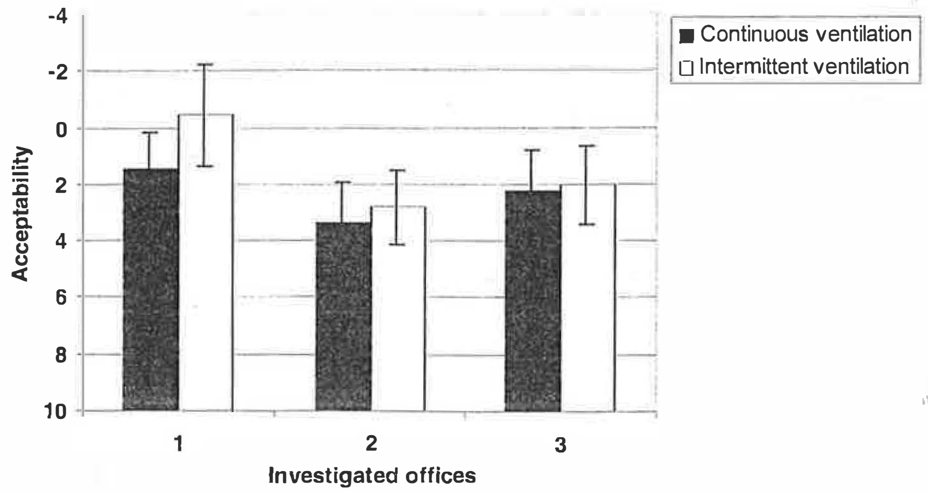
- Adaptation by the sensory panelists
- Location context of the assessments
- Psychological factors among panelists
- Familiarity and experience with the odors
- Combining materials with respect to perception and secondary processes such as sorption or oxidation

That said, in all cases the continuous ventilation strategy produced higher average ratings of air acceptability in the offices than the intermittent ventilation strategy (see Figure 3). In addition, when paint- or PVC-tainted air was diluted 9-fold, panelists couldn't distinguish the chambers containing these samples from the chamber with only supply air. As for the carpet, the 16-fold dilution produced almost the same acceptability as the supply air. The relationship between acceptability and odor intensity, the researchers report, remained stable across all tested materials.

The researchers add that the results generally show that perceived air quality improved when two new building materials were combined, and the improvement varied from one combination to another. To achieve the same acceptability of air quality when two materials are present, they add, requires a greater increase in ventilation than having only one material.

"For example, an office with a new carpet similar to the one used in this test will need approximately 14 times more ventilation to achieve an acceptability like the one of the supply air in the laboratory

Figure 3



Field measurements: mean acceptability and odor intensity votes at continuous and intermittent ventilation.

(air without strong odor). If the same office was also painted, the ventilation rate should be increased 22 times to reach the same acceptability.... Such an increase in ventilation rate is not possible in most existing buildings in terms of HVAC system capacity, cost, and comfort," they observe.

Conclusions

1. Stopping ventilation at night lowers the air quality during the day after mechanical ventilation resumes. This poorer IAQ acceptability compared to continuous ventilation is pronounced both in test chambers and in offices. Based on IAQ acceptability, stopping ventilation for half of every 24 hours may increase daytime ventilation requirements roughly four times or more to achieve the same degree of perceived IAQ.
2. Compared to a single new building material, combining two materials resulted in an improvement of assessed IAQ. The ventilation rate needed to improve the acceptability for combined materials, however, was higher than for single materials. The ventilation rate required also varied depending on which materials were combined.

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CASE STUDY

[In each issue, IEQS *presents a case study on an indoor air investigation in a particular building. The information in the cases comes from various sources, including published material, reports in the public record, and, in some cases, reports supplied by the consultants involved in the case.* IEQS *presents a variety of approaches to investigation and mitigation implemented by consultants with a broad range of experience, philosophies, and expertise. Inclusion of a particular case study in the newsletter does not imply* IEQS*'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case.* IEQS *invites readers to submit comments, suggestions, and questions concerning the case. At the discretion of the editors, correspondence may be presented in a future issue.]*

Mold Strikes Town Hall Trailer Offices in US Northeast

Officials in a small town in the US Northeast hired Tiffany-Bader Environmental of Bedminster, New Jersey, to perform a microbial survey of the community's town hall trailer offices last year.

The single-story structure, composed of two side-by-side trailers connected by a 12-foot section, measured about 1,500 square feet (ft^2) or 139 square meters (m^2). This "temporary" office space