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Commissioning HVAC Systems

One of the worst times for IAQ problems is when a building is first occupied or when it is re-occupied after modification. Building occupants have just moved, and the disruption in their lives is stressful — they are especially sensitive to contaminants or poor ventilation. Construction and furnishing materials are usually new and many emit large amounts of VOCs into the indoor air. These circumstances often cause numerous complaints and, occasionally, significant health effects. The culprit in these IAQ problems is often a new or modified HVAC system that simply isn't working properly.

Most IAQ authorities believe that thorough HVAC system commissioning will prevent many of these difficulties. Conventional HVAC system Testing, Adjusting, and Balancing (TAB) procedures do not ensure a properly functioning system under the full range of load and climate conditions; testing is done under "normal," full-flow conditions, so system performance under part-load or extreme conditions is not evaluated. Yet, extreme load conditions often reveal problem buildings. The TAB process is not intended to evaluate building performance — it is really just a procedure for setting equipment to deliver certain specified flows. It is only one component of the commissioning process.

While investigating IAQ problem buildings, IAQ consultants often find that even TAB procedures were not fully or correctly implemented. Air flows are set incorrectly in both supply and return systems, and controls are not implemented according to design intent. Some measurements simply do not agree with the design specifications or the TAB report. In the most extreme (but far too common) cases, much of the HVAC system appears out of adjustment and balance — it's as though the work were not actually performed on certain critical components.

Problems occur even in buildings adjusted by independent TAB contractors, though they are usually more reliable than mechanical subcontractors. Owners or design professionals can prevent some problems by spot-checking air flow measurements and system control effectiveness and requiring correction as necessary. A more prudent and, ultimately, more cost-effective approach is to conduct a thorough HVAC system commissioning program — it is an invaluable technique for developing good IAQ.

Last month, in our *Techniques* section, we discussed building "detoxification." We included a brief discussion of the HVAC system commissioning process. In this article, we'll elaborate on HVAC system commissioning — when a building's equipment or some portion of it is started up, adjusted, and evaluated against certain performance criteria. These performance criteria are documented during and after the design phase, but effective commissioning starts at the beginning of a project.

What is HVAC System Commissioning?

HVAC system commissioning is a process for assuring the performance of a building's HVAC system. It involves documenting and verifying that an HVAC system's actual performance meets the design intent. Formally documenting HVAC system design performance objectives and using them to guide system design, construction, and operation results in a better-functioning building. It reduces change orders, ambiguous responsibility, and poor

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Multi-Phased Testing Used to Evaluate VOC Emissions from Building Materials

IAQ research and control technology should reflect how contaminants affect people, buildings, building contents, and the environment. However, even when health and comfort effects are the driving force in IAQ activities, they are often the least understood.

Danish researchers, reporting in two separate papers at the Indoor Air '90 meeting in Toronto last July, studied how several existing test methods can increase our understanding of human reactions. They showed that a series of tests on a product, material, or assembly of building materials can provide more useful and definitive information than a single test. Sometimes, the results of different tests are at odds with each other, while other results may be more consistent.

Architects, engineers, and interior designers can use the tests during building design. Consultants can use the tests when investigating IAQ complaints. Manufacturers can also use the tests to evaluate their products before marketing them or to determine their potential liability in the event of a lawsuit.

The work reported thus far involves tests on only four separate building material assemblies and, therefore, the results only suggest the usefulness of the researchers' approach. It is dangerous to generalize from such a small set of tests. However, the results demonstrated the potential of multi-faceted testing for screening building materials.

The researchers' work shows how much the different tests' results do or do not correlate. They also showed that the appropriateness or utility of each of the tests depends, in part, on the type of effect being evaluated and the chemical substances involved.

We think the researchers' work is important. We present it in some detail here and discuss its implications as we understand them. We are convinced that their approach foreshadows building material and product testing in the next few years.

The Tests

All the test methods previously have been used separately by various researchers to test building materials, products, and individual chemical substances. But by using the tests together on each of the four typical building material assemblies, the researchers demonstrated some of the values, correlations, and limitations of the tests. Their work helps define some of the specific differences in each test's ability to predict the human effects of a test specimen's emissions.

The Materials

Four materials were studied:

1. Water-based painted wallpaper on gypsum board - 0.5 months old, 74 m^2.
2. Rubber floor covering - 8 months old, 70 m^2.
3. Nylon carpet with rubber mat - 8 months old, 72 m^2.
4. Acid-curing, lacquer-coated particleboard - 1 month old, 72 m^2.

The following criteria were used for selecting materials:

- The materials/assemblies were in general use.
- They were an integral part of various types of buildings.
- They were in direct contact with the indoor air when typically used.
- They were finished products.
- Their emission rates could be held constant (stable) during the experiment.

How The Measurements Were Made

The first set of tests was done in a climatic chamber. Human subject exposures in the chamber lasted six hours. Subjects were exposed twice to each material tested and twice to an empty chamber on ten separate days with at least one day between exposures. The chamber was kept at 22 °C, 45% RH, and 0.5 air changes per hour. The researchers measured human physiological responses by performing lung function tests and eye examinations reflecting tear film quality and epithelium damage.

The second series of tests included:

- Measuring VOC in the chamber with and without persons present.

Material	Votes[1]	Decipol	TVOC ($\mu g/m^3$)	CH_2O ($\mu g/m^3$)	Mice (irritation)	Eye[2]
Painted gypsum board	40	9.3	1,230	86	no	-2
Rubber floor	64	24.1	1,923	11	no	-4
Nylon carpet	56	20.8	1,406	26	no	-3
Particle board	54	16.4	1,109	743	yes	-1
Empty chamber	23	8.5	63	12		0

1: Mean air quality index on a scale of 0-100 (100 is worst) 2: "Eye" means Tear Film Quality Index. -4 = worst.

Table 2 - Air Quality From Four Building Materials and the Empty Test Chamber

- Headspace analysis of VOC emissions from the materials.
- Measuring and evaluating the irritating potency of the materials by mice bioassay.
- Subjective evaluation based on perception of the air quality by a trained panel (using the decipol scale developed by Fanger).

25 volunteers were subjects for the first set of chamber experiments. 20 were asthmatics and 5 were non-asthmatics. There were 13 females and 12 males with a mean age of 32 and an age range from 19 to 53.

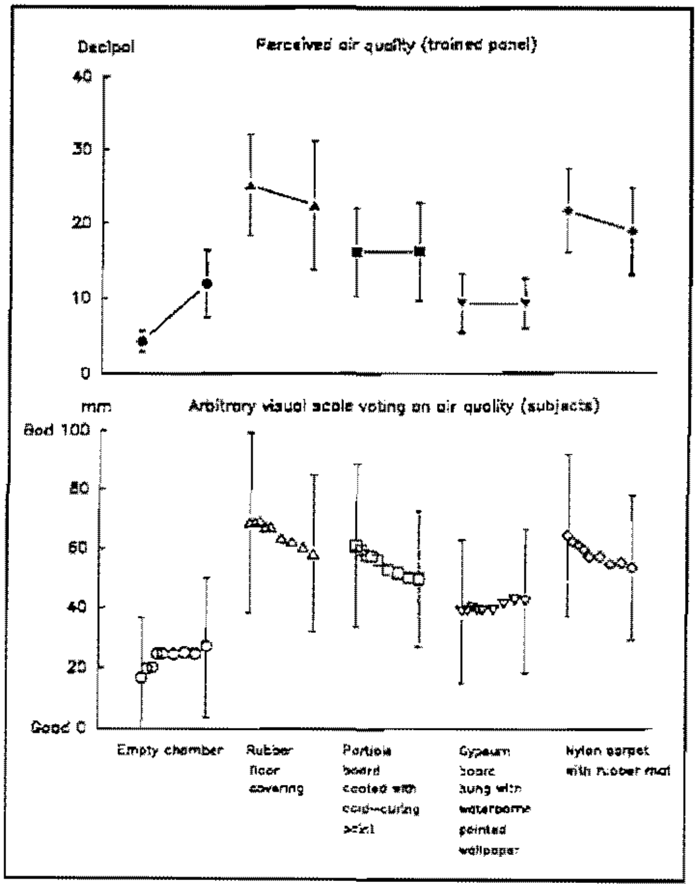

Figure 1 - Perceived Air Quality by a Trained Panel and by Test Subjects

The lung function tests included forced expiratory volume in the first second (FEV_1), forced vital capacity (FVC), and mini-Wright peak expiratory flow measurements (PEF, best of three attempts). PEV and PEF results are used to determine the presence of an asthmatic reaction. Lung function tests were performed several times during the day beginning before and immediately after subjects entered the chamber and at specified intervals while in and after leaving the chamber.

The four external eye examinations included the following:

- The appearance of foam at the eyelid or corner of the eye.
- Semi-quantitative measurements of precorneal superficial lipid layer.
- The time interval from the conclusion of a blink to the occurrence of tear film fracture - break up time .
- Staining to reveal conjunctival epithelial damage.

Subjects completed questionnaires upon first contact and before and after exposure on each test day. Additionally, subjects subjectively evaluated temperatures, drafts, and general comfort on a visually scaled range from good to bad. Daily records of eye, nose, and lung symptoms were recorded before, during, and after the exposure period.

Researchers measured VOC by collecting samples on Tenax tubes which were analyzed by GC/MS. Details of the work are available in the paper. (See the Wolkoff reference at the end of this article.) The results of the chamber tests were reported for the six (or more) most abundant compounds and noted according to available information on odor, irritancy, and guideline or legal limits.

The mice bioassay followed the ASTM E981-84, "Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals " (discussed in the article on the "Yale Conference" in the May issue of the *BULLETIN*.)

The subjective air quality ratings followed the procedures established by P. Ole Fanger. Referred to as "olf and decipol" measurements, these procedures characterize odor and calculated odor source strength based on the intensity of an odor under controlled ventilation conditions.

The Results

The investigators reported no adverse impact on the asthmatics from the exposures. In fact, of the generally 15-20% of the asthmatics reporting symptoms on arrival, there was general improvement during the exposures along with increased lung function.

Eye examination results correlated well with reported symptoms, especially for the rubber mat, the lacquered particleboard, and the carpet, and less clearly for the painted wallpaper on gypsum board.

Interpreting the results, Peder Wolkoff told the *BULLETIN*: "Highly lipophilic VOCs destabilize the tear film producing a perforated tear film." Irritants may then penetrate and dissolve in the tear fluid. The lacquered particleboard and the painted wallpaper on gypsum board "primarily emit hydrophilic VOCs" thus corresponding to less tear film destabilization. Note that the external eye examinations relate to the tear film itself. No defects of the epithelium were observed.

The researchers found a "similarity between general comfort of the trained panel [decipol] and the participants [votes]." The results are shown in Figure 1.

The results of the second set of tests (both chamber and mice bioassay) are presented in Table 2. Note the high emission rate for formaldehyde was reported as the minimum since the sample analysis showed "breakthrough" onto the back-up sampling device.

The investigators concluded that air quality votes and decipol evaluation appear not to correlate well with TVOC. Note that the decipol/TVOC ratios in Figures 2-4 are inverted because of the dominant emission of odorless VOCs from the painted gypsum board.

The response to the particle board indicates that the decipol evaluation is "...not sensitive to a strong irritant like formaldehyde. The reason for this is that the reaction time for perception and evaluation in decipol units is too short ... to be effective [for formaldehyde] and the odor perception of butanol instead takes place." The high concentration of formaldehyde resulted in both eye and throat irritation as expected from published guidelines.

Figures 2-4 show plots of the relationships between decipol ratings and various chemical measurements. The high decipol value for the rubber floor covering was consistent with the high odorant content of its emissions. The painted wallpaper had a low odorant content and received consistently low decipol ratings. The researchers recommend more detailed studies to define these relationships.

Figures 5-6 show plots of the relationships between chemical measurements and tear film quality. The investigators found that "[t]he high abundance of lipophilic VOC like aromatics and isodecene is compatible with the highest tear film quality index for [the rubber floor covering and the nylon carpet and pad]." They believe this is because these "...would have a destabilization effect [on] the lipid multilayer of the tear fluid producing perforated tear film. Irritants then penetrate and dissolve in the tear fluid. Both [the painted gypsum board and the lacquered particle board] emit primarily hydrophilic VOC thus corresponding to a lower degreasing capacity." Irritants may then act directly on free nerve endings instead of dissolving in the tear fluid.

There were some important differences between the compounds collected in the headspace analysis and those collected in the chamber study. Among them, "...the relative proportion of siloxanes was found negligible in the chamber air as opposed to the headspace analysis. A rationale for this may either be a low air exchange efficiency at the fleece surface of the carpet or adsorption (sink) on chamber walls and personal clothing." In another case, the painted wallpaper on gypsum board, the researchers speculated that the difference in chamber and headspace compounds "...may be that the emission is strongly ventilation dependent."

Implications

Peder Wolkoff told the *BULLETIN* that one of the most striking things about the study's results is the low total VOCs (TVOC/Tenax) that related to symptom reports and tear film destabilization. He says this is the lowest value ever reported to give rise to observed objective measures compatible with reported symptoms. Since several IAQ authorities have recently suggested guidelines for total VOC concentrations, the Danish work begins to establish a method for validating such suggestions. The difficulty is that the responses probably depend on the specific compounds present rather than the total VOC mixture.

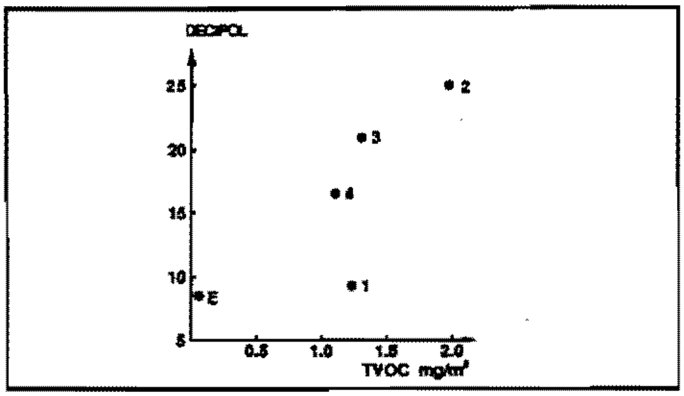

Figure 2 - Decipol Against TVOC in mg/m³

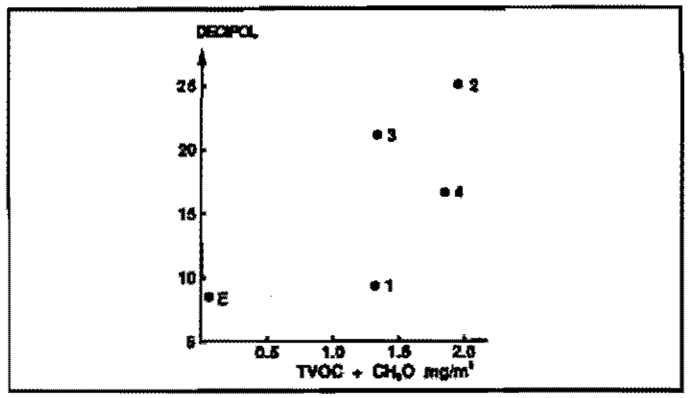

Figure 3 - Decipol Against TVOC + Formaldehyde in mg/m³

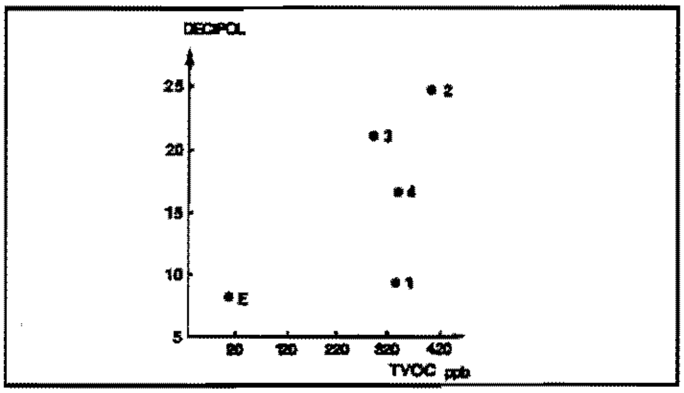

Figure 4 - Decipol Against TVOC in ppb

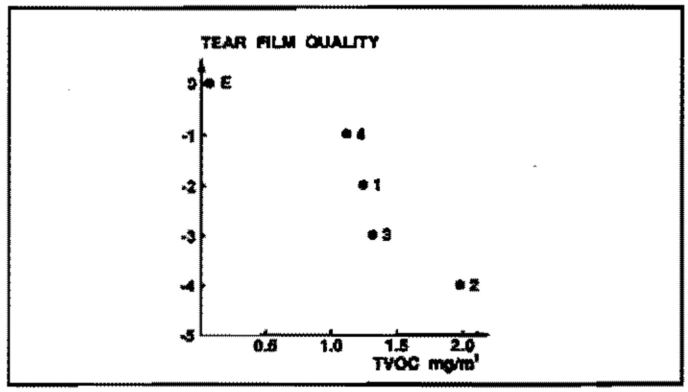

Figure 5 - Tear Film Quality Index Against TVOC

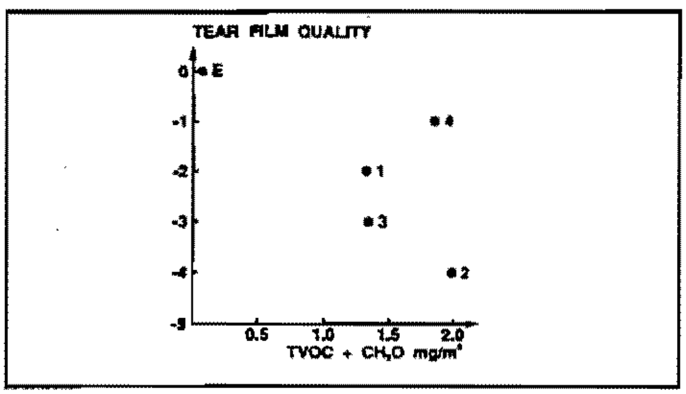

Figure 6 - Tear Film Quality Index Against TVOC + Formaldehyde

Legend

- E Empty chamber
- 1 Painted wallpaper on gypsum board
- 2 Rubber flooring
- 3 Nylon carpet with rubber mat
- 4 Acid-cured particle board

The findings of the Danish interdisciplinary study raise important questions about some methods that are increasingly being used by researchers and some IAQ professionals. They also suggest that there are some promising new methods that could be employed more widely. Among these are the following:

- It appears that the decipol is not sensitive to odorless VOCs. This implies that the decipol is a measure of odor rather than air quality.
- With environmental chamber tests of emissions from materials it may be necessary to develop methods that specifically address sink and ventilation effects on emission rates of various types of materials. Alternatively, testing with various ventilation rates might be necessary to understand ventilation impacts on emissions.
- It may be necessary to combine a series or set of tests to overcome the limitations of a single

test - at least until we obtain a better understanding of the materials.

- Characterizing VOC emissions from materials should include identifying/quantifying as many compounds as is practical. This may allow certain valid inferences regarding some of the likely human physiological and subjective responses to exposure. Less-prevalent compounds (not quantified) may also cause human responses.

References:

C.R. Johnsen et al, 1990, "Controlled human reactions to building materials in climatic chambers. Part I: Performance and comfort." In *Indoor Air '90, Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Volume 1*, pages 269-274.

P. Wolkoff, et al, 1990, "Controlled human reactions to building materials in climatic chambers. Part II: VOC measurements, mice bioassay, and decipol evaluation." In *Indoor Air '90, Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Volume 1*, pages 331-336.

Note: The researchers were C. R. Johnsen, J.H. Heinig, and K. Schmidt from the State University Hospital, Copenhagen; O. Albrechtsen from the Technical University, Lyngby; P.A. Nielsen from the Danish Building Research Institute, Hørsholm; G.D. Nielsen, L.F. Hansen, and P. Wolkoff, National Institute of Occupational Health, Copenhagen; and C. Frank, Glostrup County Hospital, Glostrup. Johnsen and Wolkoff were listed as lead authors on Parts I and II respectively.

Conference Report

Researcher Discusses SBS and Mass Psychogenic Illness

Alan Hedge, a psychology professor at Cornell University, has raised some important concerns about SBS studies that go to the core of IAQ research, policy, and control. Hedge points out that there is a lack of standardization of the methods and instruments used to study SBS. He says there is no clear understanding of how this lack of standardization confounds the results of SBS studies and hampers progress in understanding SBS etiology.

Hedge raised his concerns in a paper delivered in May at the University of Tulsa Indoor Pollution Seminar. He focused on the extensive use of "self-report questionnaires or interviews to collect symptom data." Because of this, he says, there are numerous psychological factors that will influence the results. These factors include "a worker's expectations, awareness of somatic [physical] symptoms, and his or her tendency to attribute these to the environment."

Hedge cautions that poorly constructed questionnaires can produce results confounded by "recall bias and response scale bias." Recall bias relates to factors affecting "the accuracy of our memory for events." Response bias relates to poorly designed response scales with ambiguous meanings. He cites the example of categorical scale points of "often," "always," "sometimes," etc. He says that apart from a draft ASTM standard (of which he is the lead author) "...there is a dearth of guidance on how to design an SBS questionnaire and conduct a survey of SBS complaints in buildings."

Mass Psychogenic Illness (MPI)

Hedge quotes a source that says MPI describes "the collective occurrence of a set of physical symptoms and related beliefs among two or more individuals in the absence of any identifiable pathogen." (Colligan and Murphy, 1982). According to the authors, MPI dynamics depend on two processes: contagion involving "the spread of affect or behavior from person to person in a group, where each case serves as the stimulus to be imitated by others"; and convergence, where there is "simultaneous development of common affect or behavior among group members." While these two processes are often triggered by environmental events such as a bad odor, "[i]n the absence of an identifiable cause this trigger facilitates the expression of symptoms which individuals attribute to an environmental cause (e.g., a 'mystery bug')."

Hedge goes on to say that MPI symptoms are probably not purely psychogenic in origin. They may result from interactions between pre-existing stressful physical environment and work conditions and predispositions among individuals (e.g., gender, anxiety) with a triggering event (e.g., malodor) and consequent psychosocial processes (e.g., management response to the perceived threat). The following are some of Hedge's examples of pre-existing stressful physical environment and work conditions:

- Poor ventilation.
- Poor lighting.
- Excessive noise.
- Tedious work.
- Stressful work
- Poor organizational climate.
- Poor labor management relations.

Hedge points out that people are quite suggestible when it comes to forming opinions on how environmental factors affect them. He says that when we believe our office air quality is poor — for example, containing an eye irritant — we are likely to behave in ways that confirm it; we may monitor our eye sensations for sensory information that will confirm our belief. He says we may even rub our eyes more often "thereby unconsciously creating this information." Such behaviors are quite common, Hedge says. He also points out that people's perceptions of their body are influenced by suggestions so that "[w]hen people are told about mites and fleas, many will scratch their bodies or complain of sensations of itching skin."

In office settings, workers have difficulty precisely attributing causes for their symptoms. For example, a worker with a headache does not know if it is caused by lighting, air quality, noise, VDT use, work pressure, or other factors.

Since SBS symptoms are perceptions, symptom reports are affected by the same cognitive processes that affect all other aspects of perception. Hedge gives the examples of studies where people are instructed to focus their attention on nasal congestion: this leads to increased reports of nasal stuffiness. By contrast, if instructed to focus their attention on "free breathing," nasal congestion reports decrease under the same environmental conditions.

Hedge also cites research showing that the way people understand questions may vary; this will result in different responses. For example, "shortness of breath" may mean slow, labored breathing to one person while another might interpret it to mean rapid, shallow breathing. Workers' descriptions of their symptoms and beliefs about the causes can be affected by any and all of the above influences as well as other psychological factors such as mood, attitudes, and beliefs. Hedge cites recent research that suggests "environmental illness among people with multiple chemical sensitivities suggests that their symptoms also can be explained by one or more commonly recognized psychiatric disorders, such as mood disorders, affective disorders, and anxiety disorders." (Black, Rathe, and Goldstein, 1990).

What Does It Mean?

Professor Hedge proposed a model to capture his multifactorial perspective. He says that "IAQ complaints and SBS symptom reports arise from the effects of *direct environmental* variables (e.g. exposure to pollutants), *indirect environmental* variables (e.g. worker's satisfaction with thermal conditions), and *non-environmental* variables (e.g. occupational variables such as job stress, VDT use, and individual variables such as gender, stress reactivity, etc.). He suggests that all of the factors can interact. The interactions may change the total stress load; this may change an individual's sensitivity to environmental irritants or may directly precipitate SBS symptom reports. Hedge told the ***BULLETIN*** that he believes "...SBS symptoms are real and not imaginary, but knowledge of the physical conditions at work alone will not predict symptoms because of individual differences in stress levels and sensitivity thresholds."

Comments

The description of the MPI phenomenon does not necessarily explain SBS symptom reports. The existence, importance, and even the possible dominant influence of psychosocial factors does not negate the role or importance of physical factors. While the MPI process sounds like a plausible explanation of the spread of SBS symptoms in many buildings, it is not necessarily an accurate or complete explanation of what actually occurs in a building any more than a theory of low-level VOC exposure, multifactorial theories, or others that have been offered.

We wonder if the higher reported prevalence of symptoms in women means that women are more susceptible, more affected by their symptoms, or more likely to report symptoms. Do we know? Can we find out? An interesting paper presented at ASHRAE's IAQ '89 examined the often-stated notion that women are more likely to report symptoms or that they report them more frequently. The analysis of results from studies concluded that women were more likely to report SBS symptoms. However, it suggested that the differences in job types for men and women are not adequately explained by job titles. Different job types might have different environmental exposures.

Hedge told the ***BULLETIN*** that while in some buildings there are no differences in the rates of symptom reports, and in some buildings he has found more problems among men, overwhelmingly he has found an increased relative risk of SBS for women, even when the study is controlled for job, age, time in the building, and other potential confounding variables.

We believe that most studies attempting to identify the causes of SBS have failed, at least in part, because they have grouped all the symptoms into one or two categories as though there were some specific disease entity involved. It makes no more sense to assume that all occupants of the building have one or two "illnesses" than it does to assume that all flu symptoms represent one or two types of infection. And, many flu symptoms are also symptoms of other illnesses. Most of them are also considered SBS symptoms when they occur in a building population.

The diversity of environmental factors and other factors acting on a typically diverse building population results in building-associated illness. The clear causality of some building-related illness such as Legionnaire's disease and humidifier fever does not mean that the absence of clearly identifiable physical causes indicates a psychological illness. The problem building investigation requires that we regard the symptoms individually and look for the factors in each individual's micro-environment that might be associated with their response. We might need very large and expensive studies to really get a handle on SBS. What has been considered as one or two discrete types of illness, with singular causes for purposes of investigation, has not turned out to be so.

Clearly, SBS symptoms are responses to a multifactorial environment, and their measurement and understanding are not likely to come easily. Until government and industry make substantially increased investments in IAQ research methods, we are not likely to make substantial progress addressing the concerns Hedge identifies. Among the areas most needing such investments are the development of sound questionnaire design, administration, and analysis. Some authorities would like to standardize questionnaires. It is not clear to this writer that the IAQ field is sufficiently mature for standardization to be either practical or likely in the foreseeable future.

Buildings constantly change — how can their full dynamics ever be completely characterized? There is a need to fund detailed characterization of the physical environment where a questionnaire respondent works. Simply characterizing a building by environmental measurements in a single or small number of spaces may not bring the understanding we seek. We need more thorough environmental characterizations of each respondent's environment. We also need to understand more about those people who do and don't report SBS symptoms.

ASTM Draft Standard Guide

Hedge has contributed to the conduct of field research by developing a standard guide for questionnaire development and administration. It is a draft standard (ASTM Subcommittee E06.25 on Building Performance). Copies are available by contacting the ASTM Staff Manager at 215-299-5400. Or write to ASTM, Staff Manager, Committee E06, 1916 Race Street, Philadelphia, PA 19103.

References

A. Hedge, "Psychosocial and Environmental Influences on Sick Building Syndrome," presented at The University of Tulsa Indoor Pollution Symposium, May 3-4, 1991.

M. J. Colligan and L. R. Murphy, 1982, "A review of mass psychogenic illness in work settings." In M.J. Colligan et al, (Eds), Mass Psychogenic Illness: A Social Psychological Analysis, Chapter 3, New Jersey: Erlbaum. pp. 33-55.

D. W. Black, A. Rathe, and R. B. Goldstein (1990) "Environmental Illness: A Controlled Study of 26 Subjects With '20th Century Disease," *Journal of the American Medical Association*, 264, 3166-3170.

For more information, contact Professor Alan Hedge, Ph.D., Cornell University, Ithaca, NY, (607) 255-1957.

Reviews

EC Commission's Formaldehyde Guidance Document

While formaldehyde control in indoor air has advanced considerably during the past decade, there still are valid reasons for concern. *Indoor Air Pollution by Formaldehyde in European Countries*, the latest in a series of indoor air reports from the Commission of the European Communities, contains a wealth of useful information. It summarizes health effects information, guidelines established by 11 European countries, WHO, and the United States, production data, concentration and exposure data, and much more.

The report concludes that there is no single European guideline for formaldehyde in indoor air but that one would be "...desirable in light of the closer (economic) connections among these countries." It identifies the need for both source control and ventilation to control formaldehyde levels. It says the cumulative effect of emissions from various sources should receive fuller consideration because emissions standards only control emissions from single products.

The report notes that sensitive people may complain at a concentration level of 0.1 ppm or perhaps less. It contains an extended excerpt From the "Health Risk Evaluation" prepared by the World Health Organization (WHO). The WHO report listed various "Effects of formaldehyde in humans after short term exposure" as shown in Table 3 below.

The estimated 0.5 mg/m^3 median eye irritation threshold with a reported range from 0.01 mg/m^3 to 1.9 mg/m^3 is a two-hundredfold difference in the reported range. Levels of 0.02 to 0.06 mg/m^3 — well above the reported 0.01 mg/m^3 at the lower end of the range — are quite common in modern buildings. This points to the importance of developing a clearer picture of the mechanism of action and the responses of various population sub-groups in order to develop reliable standards for formaldehyde in indoor air.

This is a valuable publication whether you are in Europe or elsewhere. As with the other publications in the series, it is available at no charge upon request.

Reference

Indoor Air Pollution by Formaldehyde in European Countries, 1990. Report No. 7, European Concerted Action, COST Project 613. Ispra, Italy: Commission of the European Communities, Joint Research Centre, Environment Institute. 23 pages.

Available from the Commission of the European Communities, Washington, DC (202) 862-9500, Monday - Thursday 10 AM - 4 PM; or, Institute for the Environment, Joint Research Centre, Commission of the European Communities, I-21020, Ispra, Varese, Italy. No charge.

	Formaldehyde concentration (in mg/m^3)	
Effect	Estimated median	Reported range
Odor detection threshold (including repeated exposure)	0.1	0.06-1.2
Eye irritation threshold	0.5	0.01-1.9
Throat irritation threshold	0.6	0.1-3.1
Biting sensation in nose, eye	3.1	2.5-3.7
Tolerable for 30 minutes (lacrymation)	5.6	5-6.2
Strong lachrymation, lasting for 1 hour	17.8	12-25
Danger to life, edema, inflammation, pneumonia	37.5	37-60
Death	125	60-125

Table 3 - Effects of Formaldehyde in Humans After Short-term Exposure

Techniques

Ventilation During Interior Construction

In last month's *BULLETIN*, we discussed the "detoxification" of new buildings. We received many comments on the article, so we developed some basic background information to support the discussion. In this article, we present this background material and some detailed instructions for the airing-out process.

Background

Many products installed in new and renovated buildings emit (off-gas) volatile organic compounds (VOCs) into the air. This is particularly true while the materials are new; they generally emit at a decreasing rate afterwards. VOCs adsorb onto surfaces and are then re-emitted into the air under certain conditions. This adsorption (a chemico-physical process at the molecular level) and re-emission phenomenon is known as the "sink effect."

It is prudent to minimize adsorption during construction in order to reduce the total exposure of building occupants when a building is completed. Research has shown that with typical building ventilation rates (0.5 to 1.5 air changes per hour) it can take adsorbed VOCs a month or more to desorb from aged building materials with very low emissions. In a newer building with stronger sources and similar air exchange rates it would take considerably longer. The emissions rate decreases asymptotically — that is, it steadily slows — and it is governed by several factors as explained below.

Adsorption is an extremely important process affecting IAQ. It is the strength of the bonding between the adsorbents and surfaces that affects the rates. Therefore, a material surface exposed to such vapors will have longer-term emissions. For example, many investigators assumed that carpet was a source of formaldehyde. In fact, formaldehyde is not used in most carpet, but it is such a ubiquitous compound that it is often found emitted from carpets. This is probably because carpet is often exposed to air or materials containing formaldehyde.

VOC Emissions and Sinks

Fractions of VOC substances in the air and on the surfaces available for adsorption tend to equilibrate if other relevant conditions remain constant (which they don't outside of research laboratories). Sources of VOC in materials within an enclosed space continually emit, adsorb, and desorb.

Several principles govern how VOC molecules move between air and surrounding surfaces and materials. The principles depend on each chemical's vapor pressure which increases with rising temperature. They also depend on the nature of the materials whose surfaces surround the air space. Some of what follows is based on research recently reported by Bruce Tichenor and his colleagues at the U.S. Environmental Protection Agency. (See the reference at the end of this article.) Other parts are based on our experience, theoretical considerations, and other published research reports. In sum, the relevant principles are as follows:

1. The higher the temperature at a surface, the greater the VOC air concentration due to emissions and re-emitting sinks. While both adsorption and desorption rates increase as temperature rises, desorption increases far faster. For tetrachloroethylene on carpet, desorption increased twice as much as adsorption when temperature increased from 23 °C to 35 °C (73 °F to 95 °F).

2. The sink effect is a function of the net adsorption rate (adsorption minus desorption).

3. While surface area is important, the character of the surface and how it affects the bonding is equally important.

   The greater the surface area available to VOC molecules for adsorption, the greater the adsorption and the more VOC molecules can be stored in the sink. The smoother the surface, the less exposed surface area there is at the molecular level. For practical purposes, the sink area available for VOC adsorption in most indoor environments is virtually infinite. Nonetheless, rough surface materials such as textiles and man-made mineral fiber insulations provide far larger surface areas than smooth surfaces such as glass, stainless steel, or aluminum. With materials such as gypsum board, wood, or resilient floor coverings, the surface areas available for adsorption depend on the texture and finish of the material.

4. For an evaporative process — i.e., emissions from sources — the greater the VOC concentration in the air, the less likely a VOC molecule on the surface will become airborne. The tendency of water to evaporate more slowly into humid air than into dry air illustrates this principle. The VOC concentration in the "boundary layer" (the adjacent gas molecules) immediately above the surface of a material is the most important factor.

5. High air velocity at the surface of a material will remove pollutant molecules from the boundary layer. Air movement at the surface will deplete the concentration of the VOCs there and replace the more saturated air with air from the air space above that is less saturated.

6. The larger the total mass of a given substance in materials used in construction or furnishing, the larger the quantity that must be removed via exhaust ventilation. Clearly, the most effective means to control indoor air pollution by VOCs emitted from materials and furnishings is to minimize the quantity of VOCs that products bring into a building in the first place.

Remedial Measures

There are several ways to deal with VOCs during interior construction. You can control the amount of VOCs brought into an area. You can temporarily ventilate an area to remove a good proportion of the VOCs. You can set up a prudent ventilation schedule. There are significant questions about a curing technique such as a "bake-out," and we discuss them below.

Source Control

The best way to minimize adsorbed VOCs is to limit the mass of VOC brought into a building. The most effective strategy is to carefully select products and specify proper application and installation techniques. There are several effective methods to do this. You can substitute high-VOC with low-VOC source products. You can also have products cured prior to delivery.

Temporary Ventilation

Once VOC-containing materials are brought into a building, the next IAQ control method is to minimize the buildup of VOCs in sinks. By increasing ventilation during and after installation, you remove VOCs from the air during periods when air concentrations are elevated. This is best done by increasing ventilation as much as possible with no recirculation. If building HVAC systems are not operational at the time strong sources are introduced, temporary equipment (including fans, ducts, and even power sources) may be needed. If ventilation is not operated during these periods and the building is reasonably tight and closed up, air concentrations will rise dramatically. This will result in a very large increase in adsorption and an inhibition of off-gassing (curing) processes.

Ventilation Schedule

A continuous (24-hr-per-day, 7-day-per-week) ventilation schedule is very important during and following the installation of strong VOC sources such as adhesives, sealants, paints, and other "wet" products. Research has not sufficiently defined how long a continuous ventilation period is needed prior to building occupancy. One Danish research group advises that a period of 130 days was necessary to effectively remove the VOCs emitted from building materials they tested. Absent any other available guidance based on competent research, we recommend a minimum period of 90 days after installing major sources or products emitting known strong odorants, irritants, and toxins. Ideally, continuous ventilation should be maintained until (and after) initial building occupancy.

Curing: Air-out or Bake-out?

Some authorities advocate increasing temperatures during the curing period so that the off-gassing (emissions) process will be accelerated. This is called a "bake-out." One important and unresolved question is whether this will drive more VOCs out of their sources and load up the sinks during the bake-out - resulting in higher rather than lower occupant exposures to VOC. More research and experience will help determine the answer. Clearly, the temperature increase during the bake-out period will be reduced by increasing ventilation except when outdoor air is very warm.

There is another important problem with the bake-out approach. Higher temperatures with minimal ventilation may excessively dry materials such as wood framing and finishes, caulks, sealants, millwork, and artwork. Shrinkage, warping, and cracking of materials and components has been documented in some bake-out projects. Excessive or unusual heating may violate some manufacturers' warranties.

Recommendations

Some projects' construction schedules call for an operational ventilation system prior to installing carpet and interior finishes. This is fortunate when it occurs; ventilation systems may be operated without the additional cost of temporary equipment. We strongly recommended that the HVAC system be operated continuously when finishes and furnishings are installed to minimize the build-up of VOCs in sinks. When necessary, install temporary ventilation to provide the required ventilation to minimize the VOC sink effect. Following are the elements of this ventilation procedure:

1. Run supply fans at maximum capacity consistent with maintaining acceptable temperatures for construction work. The comfort and health of construction workers should govern the temperature and ventilation control while maximizing air exchange and avoiding recirculation. Order economizer or purge-cycle ventilation mode whenever practical.

2. Run fans 24 hours per day. This way, nighttime cooling will help prevent excessive temperatures where cooling systems are not available. The nighttime operation will also help reduce accumulated VOCs in sinks since emissions occur around the clock. In no case should the building be left closed up without ventilation during the nighttime or weekend periods after new materials have been installed.

3. Have the HVAC system supply all outside air without recirculation or use of the return air system. This will minimize the accumulation of VOCs in air handlers, ventilation ducts, and sound traps with fibrous linings: these materials have very large surface areas.

4. Route exhaust through openings in the building exterior. Doors, windows, and smoke exhaust systems can provide adequate exhaust for most building locations. In some locations it may be necessary to temporarily remove glazing to provide sufficient pressure relief. Alternatively, it may help to use portable fans to move air out of spaces where high VOC concentrations are present from construction materials or furnishing installations.

5. Never turn the ventilation off for more than a few hours, and then only to work on the ventilation system itself. Ideally, maintain some ventilation at all times.

6. If ventilation is run during construction, you must change the filters (with dust and adsorbed VOCs) before occupancy.

7. Operate the ventilation system during the initial occupancy period with maximum achievable outdoor air consistent with necessary thermal and humidity control. Ventilation should be provided 24 hours/day, 7 days/week for at least four weeks after initial occupancy. Thereafter, the hours of operation and fraction of outside air may be reduced incrementally until the normal (design) operating cycle is achieved.

8. Monitor occupant reactions during the initial occupancy period. To do this, use a short subjective evaluation form filled out by a small but representative sample of building occupants each time they enter or leave the building. By tracking the results of this evaluation, building management can determine whether the rate of reduction of the ventilation has an acceptable impact on occupant perceptions and reactions and adjust it accordingly. Odor, subjective air quality, comfort, and health symptoms can be rated on a linear scale and the responses plotted using a spreadsheet computer program to determine if any rapid changes occur.

References

Bruce Tichenor et al, (1991) "The Interaction of Vapour Phase Organic Compounds with Indoor Sinks," *Indoor Air*, Vol. 1, No. 1, 23-35.

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Comments Are Welcome

If you have comments about the recommendations in this article or suggestions to share with our readers, please do not hesitate to send them to us at our editorial office.

Letters

Dear Hal:

My congratulations on a great first issue and the timely observations and questions on ventilation. I was delighted to see someone put ventilation in a little clearer perspective. I would add to your conclusions that most ventilation standards, such as ASHRAE 62's Table 2, are based on occupancy levels; yet most contaminants are people-impervious. When we ignore sources and rely on ventilation, we may be doing a great disservice to people in low occupancy areas. It seems we have also failed to fully appreciate the health considerations when increased ventilation lowers humidity, particularly in the winter in the northern climates. Finally, much has been said about NIOSH's 52-53%, as you point out, but little has been said about the 47-48% that will NOT be treated by ventilation.

I was also delighted to see a letter from Barney [Burroughs] on filtration. As you know, ASHRAE 62 doesn't treat filtration adequately and the IAQ industry has been way too quiet on the subject.

I do want to thank you for mentioning my book, *Managing Indoor Air Quality*, in your first issue. I would, however, ask you to offer your readers a correction. I am not a mechanical engineer; my degrees are in public administration. The emphasis on HVAC systems grew out of two factors: (1) many IAQ problems can be traced to poor operations and maintenance, particularly in HVAC systems; and (2) this is an area where owners and facility managers can make a difference as to potential or existing indoor air problems.

I did draw on my years of work n the energy efficiency field, but the HVAC section is written in "lay" language, as it might appear in a facilities manual. The targeted primary audience for the book is not engineers, but owners and facility managers.

To me a really key part of the book, and the result of many hours of research and labor, is not the HVAC portion, but Tables 4.6 and 4.7. These tables represent an effort to work from the owner/manager's perspective of what is first made known to them: possible contaminants, to primary sources and finally incorporate environment/physical conditions. The tables, of course, are far from perfect as many symptoms are common to several indoor air problems and are multifactorial. Anyway, they offer a starting place; not a final solution. I am indebted to EPA, particularly Dave Mudarri, for critiquing the tables.

Again, many kudos for a great first issue. I look forward to the next.

Sincerely,

Shirley Hansen, Ph.D.
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