Indoor Air BULLETIN™ Hal Levin, Editor

Technology, Research, and News for Indoor Environmental Quality

Volume 2 Number 7

Building Bake-outs

Many people use the building "bake-out" as a way to control indoor air pollution episodes. While the procedure is appealing as a quick fix to an IAQ problem, its use is itself problematic. The data available from bake-outs that have been reported in the literature are inconclusive regarding the procedure's efficacy. And, there are alternatives that are effective without many of the costs, difficulties, and risks of the bake-out procedures.

In brief, the bake-out procedure is the extraordinary heating and subsequent ventilating of a building or space in order to accelerate the emission and removal of volatile organic compounds (VOCs). Generally speaking, a building (or space) is first vacated. Its internal temperature is then raised using the HVAC system alone or with additional heat sources; the heating increases the emission rates of VOCs. After the heating period (and sometimes during it), ventilation is maximized to flush emitted VOCs from the building air.

Outdoor weather conditions, building thermal mass, and the building's HVAC system capacity determine the maximum achievable temperatures. Maximum outside supply air flow rates determine the maximum ventilation potential. The suitability and effectiveness of a bake-out procedure greatly depends on both these and other factors.

The results reported to date in the published literature are mixed with regard to the effectiveness of bake-outs. Some compounds' concentrations have clearly been significantly reduced while others have been affected less. Some concentrations have even increased in some cases. But there is currently far too little information available to draw conclusions about the general effectiveness of the procedure. More research is needed on the basic processes of emission, adsorption, and desorption under varying conditions to develop truly reliable models for predicting the effects of a bake-out.

Background

Air quality problems frequently occur after the initial occupancy of new buildings or after existing buildings are renovated. At these times, the most important contaminant sources are usually newly installed finishes and furnishings. Since most of these sources emit a large fraction of their total lifetime emissions during the first few days, weeks, or months after their installation, indoor contaminant concentrations are unusually high during these times. The problem is often exacerbated by newly-installed ventilation equipment that is not properly balanced or fine-tuned.

Not unexpectedly, occupant reactions may include headaches, irritation and itching of the skin and eyes, upper-respiratory-tract irritation, tightness of the chest, difficulty breathing, and coughing. In these cases, there is a heightened awareness of the air quality problems and a strong interest in controlling pollutant concentrations. Building owners and occupants alike turn, often out of desperation, to the bake-out to mitigate the problems.

Unfortunately, the bake-out is usually conducted over a weekend: sometimes, a three- or four-day weekend. This is simply not enough time to heat materials sufficiently and cause a significant outgassing. This short a heating usually only affects VOCs adsorbed on surfaces and some surface coatings that are still drying. However, removing these VOC could be accomplished simply by increasing ventilation without the heating. And, since building occupants tend to experience cooler air as "fresh" and warmer air as "stale," heating can cause the

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P.O. Box 8446, Santa Cruz, CA 95061-8446 (408) 426-6624

unwanted side effect of perceived poor air quality if the building is still warm from the bake-out.

Potential Problems

While the bake-out procedure may help reduce exposure to certain VOCs, at least for some time period, it is also fraught with difficulties and potential problems.

- It normally requires a minimum of several days to a week to have any significant long-term effect. During this time the portion of the building being baked out cannot be occupied.
- Its planning and execution require substantial skill and experience.
- It usually requires deviations from the plan.
- The required overriding of building mechanical ventilation system controls can cause expensive equipment damage.
- It is time-consuming and, therefore, costly in terms of real estate holding costs (rent, mortgage payments, insurance, etc.).
- Labor costs for its proper planning and execution are expensive even when nothing goes wrong.
- It may damage building materials, equipment, furnishings, and art objects. Recently, researchers cautioned a bake-out operator to not leave any chocolate lying around.
- It can increase occupant exposure to certain contaminants, especially if post-bake-out ventilation is inadequate.

We usually do not recommend the bake-out procedure. We will occasionally recommend it be considered only if certain important conditions are met. However, based on the small number of bake-outs reported in the literature so far, these conditions are rarely met. And unpublished information we have received from facility managers and others indicates they are almost always tried only over a weekend.

Instead of the bake-out, we usually recommend continuous maximum outside air ventilation for an extended time period. We also recommend operating at the lowest acceptable temperatures while the building is occupied. This, we believe, is virtually as effective as a bake-out without the potential hazards involved in a poorly conducted bake-out or one in which unexpected problems arise.

Factors Affecting Bake-Out Success

Factors determining the effectiveness of building ventilation and/or bake-out procedures to ameliorate indoor air pollution include:

- Sources
- Weather
- HVAC system characteristics
- Building characteristics
- Other factors

Sources

Total mass, area, and thickness of materials that are to be affected. While most bake-outs will have their major effects on VOCs on or near surfaces, mass is significant in terms of the relative impact of the bake-out on short- and long-term emissions. The larger the mass of VOC-containing materials, the more overall potential they have for emissions. The larger the fraction of that mass that is close to the surface, the more likely the bake-out will affect them.

For example, consider a relatively thick material such as a 5/8 inch (1.5 cm) particleboard substrate for a table. Because of its thickness, the bake-out will have less effect on the total lifetime emissions of the particleboard's formaldehyde. The opposite is true for very thin materials such as surface coatings: paints, varnishes, waxes, etc. Most of their mass is fairly close to the surface.

The importance of a material's area follows from the comments above on total mass. The more area, the more potential contribution of emissions to the air. The larger the surface to volume ratio, the more quickly the emissions will occur and the more effect heat or ventilation will have.

Volatility of VOC. Highly volatile compounds will be most affected by a bake-out. On the other hand, these compounds are emitted fairly rapidly anyway, so a bake-out may have a more practical effect on the less volatile compounds. In fact, it may increase concentrations of semi-volatile compounds (SVOC) to levels that will cause problems that would not otherwise occur.

Thermal mass of the target sources and the materials with which they are in contact. The length of time it takes for a material to heat up or cool down depends on its "thermal mass." This is determined by multiplying its specific heat by its density and is expressed as $Btu/ft^3 \bullet °F$ ($kg/m^3 \bullet °C$). If water has a *relative* thermal mass of 1, stone and concrete have a thermal mass of about 0.5; gypsum board is about 0.2, and plywood is about 0.16.

Impact of Pollutant Air Concentration. As VOC concentrations in the air increase, their emission rates decrease. This is due to the impact of the air concentration on the partial pressures of the VOCs in air and in the emission sources. The higher the pollutant concentration, the more pressure it exerts over the surface from which the same pollutant might be emitted. The rate of emission is controlled by the equilibrium vapor pressure for the particular temperature and the vapor pressure is a function of the log normal of the Kelvin temperature. Thus, the normal plot of the vapor pressure is curved upward; it is a logarithmic function. In theory, heating is beneficial at more than a linear rate. Example plots of vapor pressures for three common indoor air contaminants are shown in Figures 1, 2, and 3.

An excellent way to understand this relationship is to imagine a pan of water in a desert and a pan of water in a humid bathroom. Of course, the water that has dry air over it evaporates faster. The same is true of any chemical. If fewer molecules of the substance are already in the air, then more of it will escape (evaporate, off-gas, whatever) from the pan.

Bruce Tichenor and his colleagues at EPA have studied the rate of evaporation or desorption versus the rate of adsorption of some VOCs on common indoor materials. Their work is reported in the reference at the end of this article. Tichenor's advice based on this and other studies is that ventilation is critical to decreasing exposure and that bake-outs with minimal ventilation just re-distribute the VOC on other surfaces in the building.

Weather

Air temperature and humidity. In cold weather, more system capacity and energy expenditures will be required to elevate indoor temperatures while ventilating. Also, when cold air is heated, moisture is removed. Cold, outside air is usually relatively dry anyway. Supplying heated dry air may excessively dry out building materials and contents.

In warm weather, of course, it's easier to elevate temperature inside. However, humidity is an issue. In dry climates, even moderately heating warm outside air can result in very dry indoor air and problems for materials that are humidity sensitive. Also, indoor air humidity affects formaldehyde emissions; the higher the humidity, the higher the air concentrations of formaldehdye which is very soluble in water.

Air Quality. If outside air is contaminated, particularly with VOCs, bake-outs may be less effective and may introduce more outside source VOCs than would otherwise be present. Also, outside air that is high in fine particulate matter may soil interior materials.

If ozone concentrations are high outdoors, the introduction of large volumes of outside air can transform many VOCs into other compounds with different characteristics. In some cases, the newly formed compounds may be more irritating than the original ones. Charles Weschler of Bellcore in Red Bank, New Jersey, addressed this issue in his study reported in the article referenced at the end of this one. He found that ozone at levels not unusual indoors decreased the concentration of 4-PC emitted from new carpets but increased total VOC and concentrations of higher molecular weight aldehydes that might be irritating compounds.

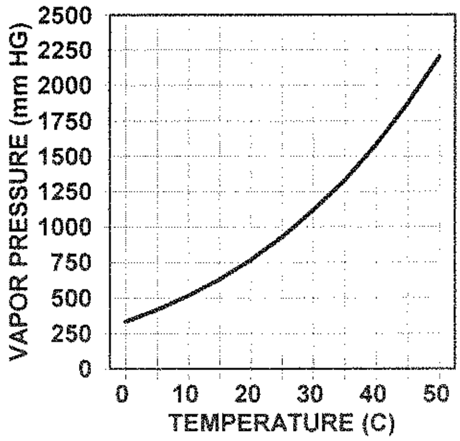

Figure 1 - Acetaldehyde

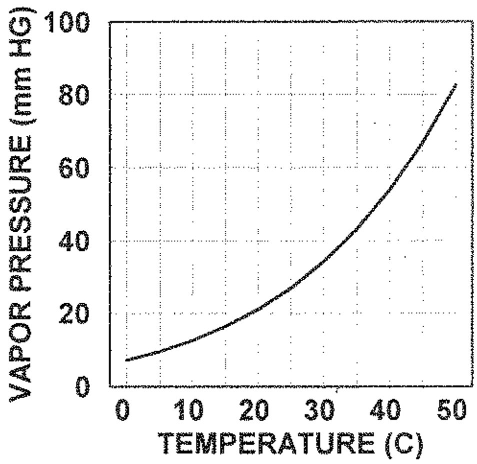

Figure 2 - Toluene

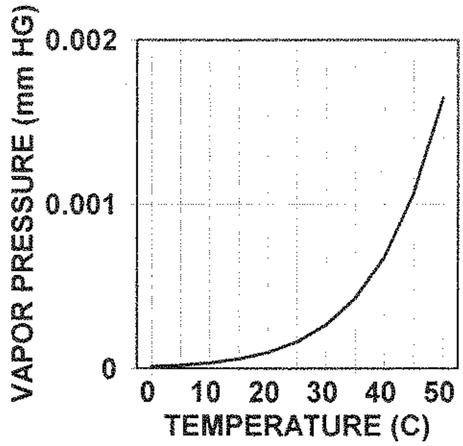

Figure 3 - Dibutylphthalate

Figures 1, 2, and 3 - Vapor pressures as functions of temperature for three common indoor air contaminants.

HVAC System Characteristics

Fraction of outside air possible with HVAC. We believe it is important to supply as much outside air ventilation as possible both during the heating period and especially during the post-heating "airing out" period. Increasing outside air flow will be in conflict with heating objectives if outside air is cooler than indoor air. Also, not all HVAC systems are capable of all outside air flow to occupied spaces. In fact, many systems in large buildings, and office buildings in particular, are capable of only 10 to 15% outside air. This usually results in no more than one air change per hour (ach). This is not necessarily sufficient air exchange for the post-bake-out ventilation regime to be effective. Therefore, occupants may experience higher VOC concentrations upon re-entry as a result of the bake-out if the post-heating ventilation period has not been sufficiently long. Since many building operators attempt bake-outs on two- or three-day weekends, this limitation can be important.

Maximum achievable outside air exchange rate (ventilation rate). In order to minimize air concentrations of VOCs after a bake-out, it is important to thoroughly flush the air with "clean" air before re-occupancy. The higher the rate of outside air exchange, the faster and more completely the building can be completely flushed. There is a wide range of maximum possible air exchange rates for buildings with mechanical ventilation only. The rates vary from around 0.6 ach to up to 6 or 7 ach for most building types. Office buildings typically are designed to have total flows ranging from 0.5 cfm/ft^2 to 1.0 cfm/sf (0.236 to 0.472 L/s) and outside air fractions from 10% up to 100%. Effective ceiling heights range from 8 to 11 ft (2.44 to 3.35 m). Thus, for a worst case scenario of 0.5 cfm/sf, 10% outside supply air (OSA) by design, and a 10-foot ceiling height, the OSA ventilation rate would be 0.3 per hour. By contrast, the hypothetical best case would be a 1.0 cfm/sf air distribution rate, 100% outside air, and an 8-foot ceiling height giving a ventilation rate of 6 ach. Figure 4 shows building ventilation rates with varying outside air fractions, supply air flows, and ceiling heights.

Total air flow capacity. The amount of total air flow possible within the occupied spaces is critical to creating good air movement at surfaces and eliminating stagnant air that will tend to suppress emissions. Some investigators have recommended portable fans to assure good mixing and air movement in bake-out spaces. Total air flow includes both outside air and recirculated air. Volumes and velocities at material surfaces will be a function of distributed air flow rates and distribution of materials relative to air supply and return locations.

Heating capacity of the HVAC system or other heat source. Since the principle of the bake-out includes elevating temperatures, it is critical to determine just how much heating can be done in a given building and climate regime. The heating capacity of the building equipment may need to be supplemented with portable (although not necessarily small) heaters. However, the portable, powerful heaters are usually gas-fired and they may create additional problems. The pollutants they emit include some VOCs and, especially, fine particulate matter.

Control system characteristics. A bake-out nearly always requires overriding control system settings. Control components including thermostats and HVAC system control computers will need to be adjusted. And, HVAC system conditions and performance must be monitored continually throughout the bake-out. Direct digital control (DDC) systems facilitate much of the work but still must be verified with field measurements and observations.

Building Characteristics

Thermal mass and its distribution within the building. The time required to heat a building is a function of its total thermal mass and heat transfer through the building envelope. Concrete and masonry structures generally have more thermal mass than steel or wood-frame structures. Even so, steel structures usually contain a substantial amount of concrete or other cementitious material. It is also important to remember that the longer it takes to heat the building, the longer it takes to cool down. Thus, there must be sufficient time and ventilation after the super-heating is completed to reduce the emission rates of materials that are warm or are in contact with warmer surfaces such as concrete floor slabs and structural members. Girman *et al.*(in the 1990 reference at the end of this article) reported that measured VOC concentrations did not decline completely from their

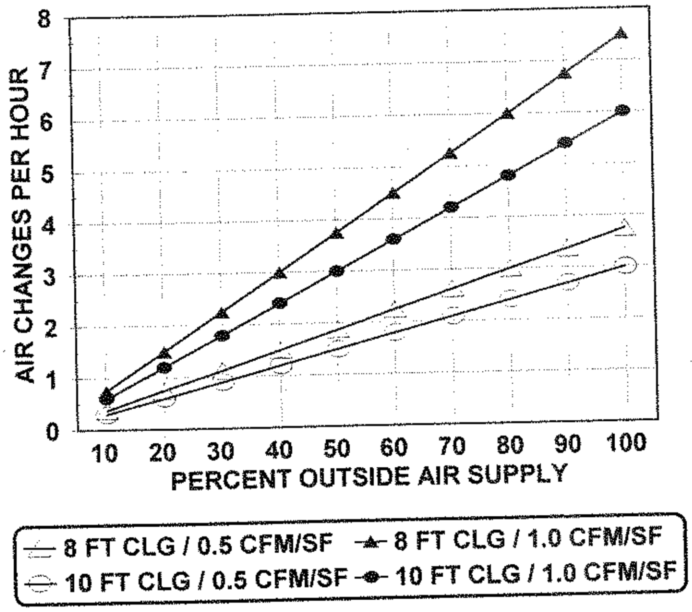

Figure 4 - Building ventilation rates with varying outside air fractions, supply air flows, and ceiling heights.

heating-phase concentrations until the building had cooled down.

Type and distribution of materials containing offending VOC. Above we mentioned the difference between emissions from surface materials and from thicker materials. Similarly, if a source of VOC is encapsulated or covered by another material, the VOC will have to diffuse through the covering material to reach the air. Examples are formaldehyde in particleboard that is used as underlayment below floor coverings or as a substrate in furnishings that have plastic-laminate surfaces.

Another example is carpet cushion (padding). Any VOC emitted from the cushion during the bake-out must travel through the carpet to reach the air. The carpet itself consists of several layers. The lower layers may be fairly impermeable to the gas-phase VOC, and the uppermost fiber layer is a virtual forest of surface material which can readily trap gas molecules passing through it. It is, therefore, especially hard to effectively remove VOC from carpet backings and pads through a bake-out unless it is very long and involves very high ventilation rates at the carpet surface. Tichenor reported on his tests of airing out new carpet in which he showed considerable benefits from three-weeks of ventilation without heating. His results are contained in the reference to the *Carpet Policy Dialogue Compendium Report* at the end of this article.

Other Factors

Time available for bake-out. Considering the factors we've discussed, most buildings will require no less than three to four days, and usually something approaching a week, to experience a significant rise in temperature. We strongly recommend that a couple of extra days be planned as a contingency measure – just in case something goes wrong during the bake-out. Thus, at least a week and more reasonably, ten days are required for a well-executed, effective bake-out procedure.

Responsible personnel's knowledge of the building, the target sources, and the HVAC system. Experience has shown that unexpected problems often occur during a bake-out. There is no substitute for knowledgeable, experienced building operating personnel to manipulate the building and to respond to problems if they arise.

Temperature and vapor pressure. The actual impact of bake-out heating on VOC emissions is a function of the vapor pressures of the VOCs in question and their distribution within the materials and the building. Since building temperatures are usually between 70 and 75 °F (21 to 24 °C) and bake-outs usually do not achieve more than 95 °F (35 °C), 20 to 25 °F (11 to 14 °C) is the typical maximum increase that can be expected.

John Girman *et al.* reported that an increase from 23 °C to between 32 and 39 °C during a bake-out would be expected to increase the diffusion of solvents through materials about 10% and to increase vapor pressure of solvents about 200%. (See reference to 1987 article.)

The Role of Ventilation. Evaporation of chemicals from surfaces increases if the partial pressure of the chemical on the surface is higher than that of the chemical in the air immediately above. If air movement at the surface is sufficient and the concentration of the chemical in the air is low enough, the partial pressure difference will be larger, even where the vapor pressure of the solid, liquid, or condensed phase chemical is rather low. Therefore, it is important that air movement be assured over all surfaces during a bake-out. This is also true for the maximum ventilation approach to mitigation.

Required Conditions for a Successful Bake-Out

The following conditions must be met for a successful bake-out:

- The bake-out and following outside air ventilation period should be no less than six to seven days total: at least four for heating and two for all outside air ventilation. The actual amount of time clearly varies as discussed above.
- There must be competent and effective control of the building ventilation system for the areas targeted for the bake-out. Newly installed ventilation systems are often not easily controlled as designed, expected, or desired.
- There must be no fine art, furniture, or woodwork (or chocolate) in the bake-out zone that may be adversely affected by extremely low humidities and high temperatures.
- The HVAC system must be capable of supplying sufficient outside air to flush the building at temperatures in the required range while outdoor air temperatures are in the normal expected range for the time of the bake-out.
- There must be qualified personnel monitoring the bake-out 24 hours per day throughout the entire bake-out period.

Discussion

It is important to point out that bake-outs should be unnecessary if proper design and construction measures are implemented. These include the selection of low-emitting materials and the use of adequate ventilation during construction and initial occupancy.

There needs to be more research on the emission, adsorption, and re-emission of important indoor VOC pollutants on major indoor surface materials such as concrete, gypsum board (painted and unpainted), wood (finished, unfinished, rough, and smooth), thermal, fire, and acoustic insulation, fabrics, carpets, and ceiling tiles. Only after we get more empirical data can we model and accurately predict bake-out procedure effects. We also need to know much more about the impact of bake-outs on semi-volatile compounds.

Control By Temperature

Researchers at Yale University's Pierce Laboratory have shown that lower temperatures will result in better perceived air quality. Actually, they showed that the higher the temperature, the worse subjects perceived the air quality to be while its actual quality remained unchanged. Therefore, where there are reports of poor air quality in newly furnished, refinished, or constructed spaces, we recommend operating at the lowest comfortable air temperatures. These will be around 70 °F (21 °C) with humidities and air movement in the normal range.

Mitigation by Ventilation

Rather than mitigate an IAQ problem by bake-out, we usually recommend that the maximum ventilation possible be used. This includes operating on maximum outside air continuously – 24 hours per day, 7 days per week. Ideally, this thorough ventilation begins before occupants enter newly constructed, remodeled, or furnished spaces and continues for several weeks after construction is completed. If it is begun when the building is closed in and VOC source materials such as adhesives, paints, and furnishings are installed, a bake-out will not be necessary.

We invite readers with well-documented bake-out experiences to share them with us. We'll pass them along to our readers.

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Acknowledgements:

Our thanks to the following who helped us formulate our thoughts for this article: Bruce A. Tichenor of EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, North Carolina; John R. Girman, Chief, Analysis Branch, Indoor Air Division, EPA, Washington, D.C; and, Charles J. Weschler, Bellcore, Red Bank, New Jersey.

Building Investigation Techniques

Engineering Analysis

An engineering analysis is one of the most important and effective tools for investigating problem buildings. Its use often helps identify deficiencies in a building's design, construction, or operation that contribute to IAQ problems. Based on an engineering analysis, building operators can often resolve problems more economically and quickly than by determining the precise causes of occupant complaints through air sampling or occupant surveys. In this article, we discuss the engineering analysis in the context of the generic "building investigation" (sometimes called "building diagnostics") related to indoor environmental problems.

Why an Engineering Analysis?

The purpose of an engineering analysis is to determine the ability of a building (or its design) to handle contaminant and thermal loads. Inadequacies can result from poor design, construction, or operation, or can result from occupants' improper use of the building. Problems may also result from poor communication of the design intent to the operators, from inadequate training of building operators, from a lack of sufficient operator control over building operations, or from a malfunction in the building equipment.

Three Phases of a Building Investigation

In its most widely advocated form, a building investigation consists of three main phases: 1) Consultation and problem definition, 2) Qualitative diagnostics, and 3) Quantitative diagnostics. The least expensive and most productive parts of a building investigation are usually the first and second phases. Environmental problems that cannot be resolved during these initial phases are less likely to be resolved by the extensive and expensive measurements that are usually part of a third phase.

Details of building investigations vary dramatically from one case to another because of the unique nature of each building and the environmental problems leading to the investigation. Often, when a formal investigation begins, there have already been efforts to identify and resolve problems. The building operators, occupants, or consultants may have already measured air quality, ventilation system performance, or other parameters. They may have tried to address complaints by modifying the ventilation system, reducing contaminant sources, or by taking other measures. The situations investigators encounter are usually quite unique in each building.

Phase One: Consultation and Problem Definition

This first phase involves discussions with responsible and affected parties. It usually includes phone calls, meetings, and interviews, and possibly a walk-through of the building and inspection of the affected spaces, ventilation system, or other equipment. The purpose of this phase is to define the scope, goals, and objectives of the investigation and to establish the extent, nature, and time frame of the building problems. Ideally, investigators formulate hypotheses that can be tested in the subsequent phases.

Investigators may administer questionnaires, conduct interviews, or use other techniques to develop a systematic picture of the nature and distribution of health and comfort problems. They may augment their professional team to include experts in microbiology, VOCs, ventilation, psychology, or survey research. The nature of the investigation and the problem resolution generally reflects the expertise of the lead investigator. Dr. Lars Mølhave of Åarhus, Denmark, pointed this out at Indoor Air '87 in Berlin. Engineers find engineering problems, physicians find medical problems, architects find building problems, and psychologists focus on perceptual and attitudinal problems.

Based on this initial phase, skilled investigators often can identify building problems or contaminant sources that may be responsible for air quality problems and/or reported occupant health and comfort symptoms. In many cases, initial diagnostic success will end an investigation. However, the nature of the occupant health problems may warrant immediate medical attention. Examples include reports or suspected cases of Legionnaire's disease, Pontiac fever, hypersensitivity pneumonitis, or epidemic infectious disease.

Phase Two: Qualitative Diagnostics

If at this point solutions are not evident, the second investigation phase, referred to as the "qualitative diagnostics," is planned. It involves a detailed inspection of the facility, occupied spaces, and HVAC equipment and may include measuring basic environmental parameters. Most investigators measure temperature, humidity, and, perhaps, CO_2 during this phase. Investigators identify, in detail, specific characteristics of important contaminant sources and of the building- and personnel-based environmental control systems.

This is when investigators should consider an engineering analysis. It facilitates a more detailed and systematic understanding of the building and especially the environmental control systems. It provides a chance to investigate the building in a non-intrusive manner that is often more productive than measuring or inspecting occupied spaces.

Phase Three: Quantitative Diagnostics

The third phase, quantitative diagnostics, involves measuring building performance and environmental parameters. Normally it requires extensive instrumentation and a substantial cost. To be effective as a diagnostic tool, the measurements should be planned on the basis of hypotheses developed during the previous stages. A broad-spectrum air sampling and analysis program can be very expensive and is highly unlikely to reveal the causes of occupant health and comfort problems. The most effective measurements verify contaminant sources, ventilation system deficiencies, or other hypothesized factors in the reported health and comfort problems.

Project Phase	Problem Type	Possible Causes
Design	Insufficient load information.	Unknown tenancy or occupant activities.
	Inaccurate load information.	Poor client-designer-engineer communication.
	Inappropriate capacity (too large or small).	Improper design.
Construction	Incorrect component installation.	Poor construction activities; unavailable components; insufficient oversight by designers, construction managers, or inspectors.
	Improper installation.	Poor workmanship.
Operation	Insufficient pollutant removal capacity.	Inadequate design, construction, or system control program.
	Inadequate system performance.	Insufficient or inappropriate operation program, schedule, modes.
	Unaddressed load changes.	Inadequate evaluation of intended space use changes, changes in density of occupants, or changes in equipment and emissions.

Table 1 - Possible causes of building environmental problems that can be identified by an engineering analysis.

Table 1 shows some possible causes of building environmental problems that can be identified by an engineering analysis. Notice that the problems can begin in any stage of a building's life cycle from design to use; they can be due to defective design, construction, or operation; or, they can result from changes in the imposed loads.

Improper Loads

In many cases, buildings (as designed) are simply not able to handle imposed loads. The engineer or other designer may not have received sufficient information on the actual loads when designing the building. This is common in tenant-occupied buildings and particularly in speculative office buildings. However, it is also common in large public or private institutions. A long lag-time between design and occupancy means that planning during design is often outdated by organizational changes that occur during the construction period.

Spaces may be used too intensively or for purposes for which they were not designed. This often happens when there is a change in tenants, when buildings are remodeled, or when building occupants move or increase their density within their spaces. It can also result from changes in occupant activities, equipment, and schedules, or when there are changes in a building's maintenance: procedures, equipment and materials used for housekeeping, pest control, and equipment maintenance.

The loads of concern relate to air pollutants, thermal conditions, illumination requirements and sources, noise, and vibration among others. A complete engineering analysis must consider these environmental loads just as an adequate building must be capable of handling them all. They can be either assumed or projected loads used for purposes of design, or they can be calculated or measured loads based on analysis or observations of the building.

Steps in an Engineering Analysis

The following are basic steps taken during an engineering analysis. The list is not inclusive; as noted in the sidebar on building investigations (see page 7), each case of an IAQ problem tends to be unique. This list is a general outline on which an investigator can build.

Step 1 - Determine the Scope of the Analysis and Identify Problem Areas

The first step is to identify relevant systems and building areas for the investigation. This helps limit the scope of the analysis to those aspects of the building that are directly relevant to a hypothesized problem. Hypotheses are formed after discussions with the client, building manager, building engineering, or other parties involved in requesting the investigation.

Step 2 - Obtain Relevant Documentation

Depending on the scope of the investigation and problem areas, the following documentation may be reviewed:

- Plans (construction and "as-builts" or record drawings).
- Specifications.
- Design calculations, program information, activity inventory.
- Installed equipment.
- Operational procedures.
- Building manual.
- Calculated loads (assumed or measured; past, present or future) including both thermal and air pollution loads.

Other written and graphic materials are obtained as available.

Step 3 - Determine Design Assumptions

Additional information should be gathered on the assumptions designers made during building design. What were the assumed or projected uses of the building? What were the loads attendant to those uses? What instructions did the designers receive regarding occupant densities, activities, schedules, pollutant source-generating activities and equipment, and other "programming" information on which the design was based? Investigators may obtain this type of information from design documents and available notes from the program for the building design. In many buildings, very little such information is actually communicated to the designer from the owner or other client. In many cases, such information is not readily available and empirical determinations must be relied upon to form the basis of the engineering analysis.

Step 4 - Identify Significant Modifications

It is important to determine what the designed building was, whether it was actually constructed, and whether it has been modified since. "As-built" or "record" drawings prepared during and after the construction are useful at this stage; however, they are not always available. Original design drawings and specifications, equipment data sheets from manufacturers, and other product and equipment submittals will help determine the nature of the system. Interviews with available designers, contractors, building managers and engineering personnel may help identify useful documents and supplement the information they contain.

Step 5 - Identify Contaminants

Determine contaminant and thermal loads as carefully and completely as possible in order to evaluate the theoretical ability of the building design and construction to handle them. A listing of possible contaminant sources and thermal loads should be available based on the walk-through and initial phase consultations. Other important contaminants may be identified by building occupants or operator reports. Contaminant sources outside the building should not be ignored.

Investigators will rely on their experience and observations to determine which contaminants are potential contributors to poor environmental quality. Identify the sources and pathways of distribution for these contaminants in order to focus the analysis on the most plausible causes of the problems. Keep in mind that pressure differences between interior spaces or between the building and the exterior are the driving forces for the movement of contaminants from one location to another.

Step 6 - Determine Thermal Loads

External and internal sources of heat or cold determine a building's thermal environment. Note that office equipment and other appliances have become important sources of thermal loads. It will be important to verify system capacity against the actual loads imposed on it.

Step 7 - Determine Equipment Capacities

The walk-through and HVAC inspection notes equipment sizes and capacities. This inspection, with notations of installed equipment labels, permits verifying the actual construction. Equipment capacities are often listed on labels attached to the equipment. Information on loads in the spaces of concern should have been obtained during the normal walk-through procedures in the investigation stages previous to the engineering analysis. If this information has not been obtained, has changed, or is otherwise incomplete or unreliable, it should be obtained by systematically observing the occupied spaces of concern (including equipment and storage rooms).

Step 8 - Identify System Operating Schedules

Operational schedules and sequences are required to create a complete data file for simulating the actual conditions and loads. Often we find building operational hours are simply inadequate or inappropriate for the actual use patterns. While occupant activity-related loads may correspond to occupancy hours, building materials, furnishings and equipment emit chemicals continuously. Systems that operate only during "normal" work-day hours may require extended schedules to adequately address building loads.

Investigators should determine the plan for the actual operation and maintenance of the building and attempt to verify its implementation based on available documentation. Computer-controlled HVAC systems usually produce records, either electronic, hard copy, or both.

Step 9 - Verify System Performance Against Criteria

By calculation or by computer simulation, evaluate the building performance against the criteria established for the building. This will help determine the adequacy of the system in-place for the loads. The simulation may be a simplified one for only a certain space where occupant health and comfort problems are prevalent, or it may be for an entire zone of the building ventilation system. It will provide a reasonable evaluation of the adequacy of the ventilation system and other environmental control systems.

Reporting the Engineering Analysis

After the engineering analysis, investigators prepare a report with an executive summary, if warranted. The report should contain a complete listing of all the information obtained as input to the analysis and a detailed description of the simulation process. Where appropriate, it should contain recommendations for remediating deficiencies.

The documentation of the process is a valuable asset for building operators and engineers. It will provide the basis for future analyses that may eliminate or reduce the occurrence of environmental problems. More often than not, the absence of clear, comprehensive information is one of the key factors in the occurrence of building environmental problems in the first place.

For more information:

James E. Woods, Philip R. Morey, and Dean R. Rask, 1989, "Indoor Air Quality Diagnostics: Qualitative and Quantitative Procedures to Improve Environmental Conditions." in N. L. Nagda and J. P. Harper, (eds), *Design and Protocol for Monitoring Indoor Air Quality, ASTM STP 1002.* Philadelphia: American Society for Testing and Materials. pp. 80-98.

VOC Studies

TVOC Indoors and Out: Large Scale Sample Results

Lance Wallace of EPA has done it again, providing us with more useful data on indoor air VOC concentrations. Wallace and his colleagues re-analyzed TEAM (Total Exposure Assessment Method) study data to determine total VOCs. He presented his results in an article published in *Indoor Air,* Vol. 1, No. 4 (December 1991). He developed and applied a new method for determining total VOC to 2700 personal, indoor, and outdoor samples previously analyzed by GC/MS. His results are interesting because they represent such a large and systematic sample base.

Methodology

The original studies, conducted during the 1980s, looked at personal, indoor, outdoor, and building VOC exposure for 20 to 30 VOCs in cities across the country. The original study quantified only the target VOC. Most of these samples were collected on Tenax, thermally desorbed, and analyzed by GC/MS. Because of the potential importance of VOC and building occupant reports of health and irritation, it was decided to consider re-analyzing the computerized records of the analyses to determine total VOC (TVOC).

The TVOC study method looked at the "average response factor" for several target chemicals representing compound classes such as aliphatics, aromatics, and halocarbons. The investigators acknowledge that the method was imprecise due to the variation in air sample composition and analytical response factor. They explored a couple of different specific analytical approaches including examining single ion current (SIC) and total ion current (TIC). They found that the differences between the sum of the individual compounds and the TVOC estimate using the SIC approach were too large. However, the differences between the TIC approach with mean response factor (instead of individual response factor for each chemical) and the sum of the individual compounds in the re-analyzed samples was 20% for the chemicals whose actual concentrations were known.

Assessing the method, the researchers found about a 24% reproducibility between the main laboratory and another lab. They concluded that the method "appeared feasible for estimating TVOC levels to within 30-60%. provided that the mean TIC RRF [relative response factor] of the 17 target chemicals does not differ greatly from the mean value of other chemicals commonly found in indoor and outdoor air."

Results

Figures 5, 6, and 7 show frequency distribution results from the sample analyses for various TEAM studies. Note that the plots are on log-normal probability paper. The unmarked tics at the right side of the x-axis on all three figures are for the 90th, 98th, 99.5, 99.8, and 99.9 percentiles.

Residences

Figure 5 shows 12-hour average personal, indoor. and outdoor TVOC levels for about 650 residences. These samples were selected to represent about 600,000 people in six geographic regions. Personal exposure is clearly higher in indoor rather than outdoor air. More than half the personal air samples were higher than 1 mg/m^3 while only 10% of outdoor samples exceeded 1 mg/m^3. The straight line plots of these data and subsequent statistical analyses show that the distribution of TVOC exposures is reasonably described as "log-normal."

Buildings

Figure 6 shows the frequency distribution of 12-hour average concentrations for samples collected inside and outdoors at 10 buildings. Three of the buildings were new and were tested one week, three to four months, and six months after completion. The new buildings account for the high concentrations shown in the plot. These buildings are described in detail in an EPA report referenced at the end of this article.

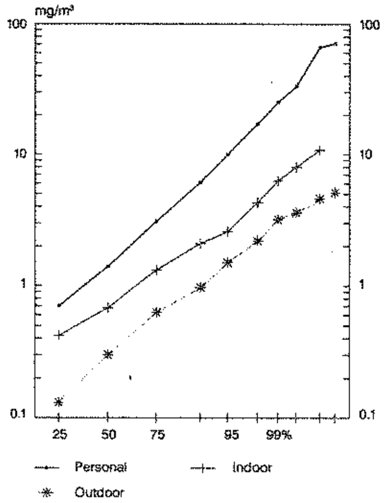

Figure 5 - Frequency distribution of 12-hour average TVOC concentrations for personal (N=1500 samples), indoor (N=198) and outdoor samples (N=326).

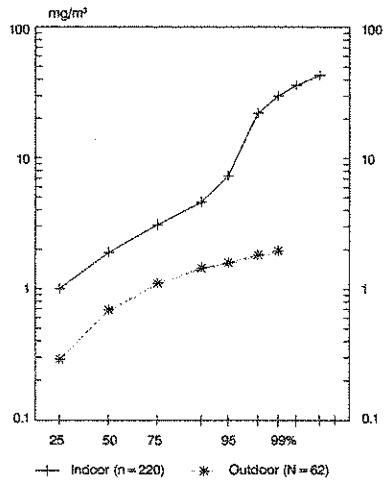

Figure 6 - Frequency distribution of 12-hour average TVOC concentrations for samples collected inside and outside 10 buildings.

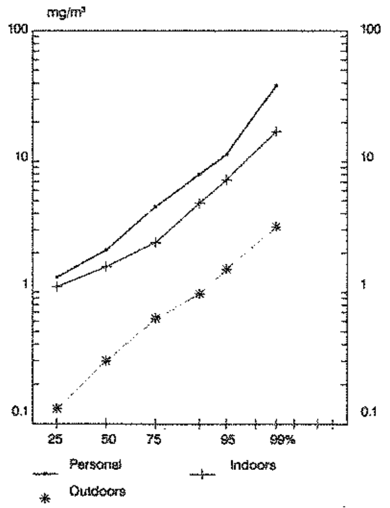

Figure 7 - Frequency distribution of 12-hour average TVOC concentrations for personal (N=135 samples), indoor (N=224) and outdoor samples (N=45) collected from 18 people carrying out high-exposure activities.

The authors note that at all three of the new buildings, seven or eight individual organic compounds were measured at 50 to 100 times their concurrent outdoor concentrations. Repeat sampling several months later showed a decline in the concentrations of these compounds to levels intermediate between the new building concentrations and those found in the older buildings. This provides a very clear picture of the decay of many VOC in new buildings as they age, and [we believe] it indicates the importance of building materials and furnishings as sources of VOC exposure.

High Personal Exposure Activities

Figure 7 shows the frequency distribution of 12-hour average TVOC exposures for personal, indoor, and outdoor air samples collected from 18 people who were involved in "high exposure activities" in their residences. More than 75% of the personal and indoor air samples exceeded 1 mg/m^3. The convergence of personal and indoor air levels was hypothesized to result from the "intensive nature" of the high-exposure activities which greatly increased indoor air levels.

Temporal Variations

Seasonal and diurnal variations are potentially significant based on the study data. Figures 8, 9, and 10 show these large variations quite clearly. Figure 8 shows data from Bayonne and Elizabeth, New Jersey that indicate twice the personal exposure in winter than summer for both daytime and overnight samples. Note the very high personal daytime winter exposure; these samples were collected in February, 1983.

Figures 9 and 10 show personal and outdoor TVOC data for Los Angeles at various times. Again there are large seasonal variations, but they differ from those in New Jersey. Daytime values are about twice to somewhat less than twice the nighttime values. The higher February outdoor concentrations are due to the unfavorable meteorology in the Los Angeles Basin involving nocturnal inversions and stagnant air. The indoor concentrations are attributed to fewer open windows resulting in decreased air exchange.

The higher daytime exposures confirm earlier observations of "the importance of personal activities in exposure to VOCs" and extend those observations to TVOCs.

Discussion

More than half the personal and indoor air TVOC concentrations exceeded 1 mg/m^3. The authors remarked that this "seemed surprisingly high." They note that several European studies have reported values below this level except in "problem buildings." For example, the authors of the Danish Town Hall Study reported a mean value of 0.5 mg/m^3 using Tenax sorbent tubes. Wallace and his col-

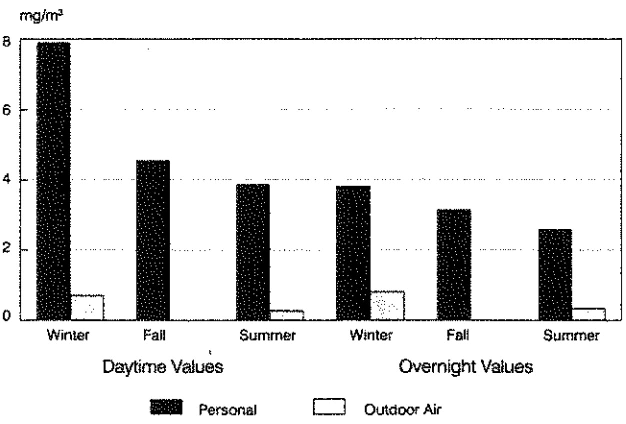

Figure 8 - Arithmetic mean daytime and overnight personal and outdoor air TVOC concentrations in Bayonne and Elizabeth, NJ during the winter of 1983, fall of 1981, and summer of 1982.

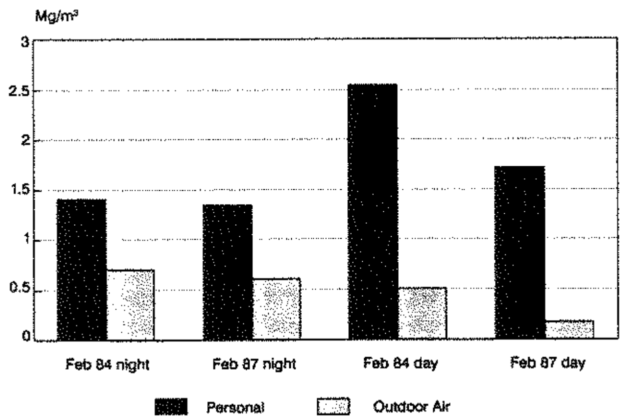

Figure 9 - Arithmetic mean daytime and overnight personal and outdoor air TVOC concentrations in Los Angeles in February 1984 and February 1987.

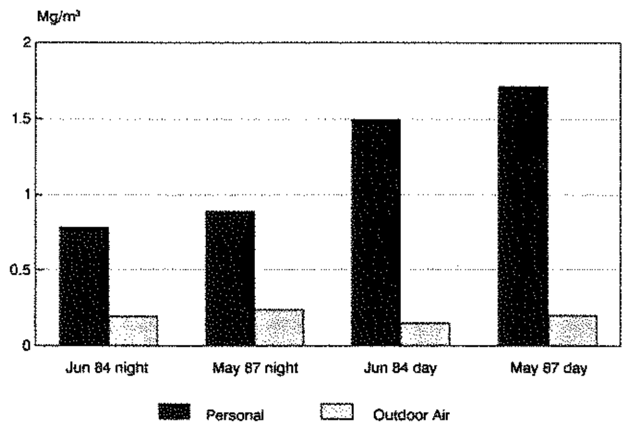

Figure 10 - Arithmetic mean daytime and overnight personal and outdoor air TVOC concentrations in Los Angeles in June 1984 and May 1987.

leagues speculate that "one possible reason for the higher values observed in this study is that the GC-FID methods generally employed in European studies are not sensitive to chlorinated chemicals, and that these chlorinated chemicals are found widely in the United States." [See the related comment by Gustafsson in the article on the FLEC on page 13 of this issue.]

The median measured TVOC values for personal and indoor air ranged from 0.8 to 2.1 mg/m^3. This was several times the median values for outdoor air, 0.3 to 0.5 mg/m^3. Thus, the personal and indoor air TVOC levels are three to five times the corresponding values for outdoor air. According to the report, "Personal TVOC exposures generally exceeded indoor concentrations during the day but not at night; this probably represents the increased exposure occurring during normal daytime activities such as commuting, cleaning house, etc."

Wallace and his co-authors caution that the reported TVOC values are "...a function of the method employed, and cannot be unambiguously compared to TVOC values calculated by other methods." They wrote that "Several methods exist for measuring total organic concentrations; however, no single reference method is accepted, and the relationships between different methods are not well characterized....[I]t is inappropriate to compare TVOC measurements using one method to those using another." We see this as a major impediment to usefully comparing results from different studies.

They recommend that existing methods of calculating TVOC be compared side-by-side for various environments. This will establish relationships that can be used to compare past measurements using different methods. We strongly support the recommendation.

The measurements can be baselines for TVOCs in indoor air in homes and buildings in several US cities. EPA is readying a major indoor air "baseline" study of buildings in various parts of the US. Wallace's work could be an important reference for the new study and for field researchers if the recommended comparison studies are carried out.

References:

L. Wallace, E. Pellizzari, and C. Wendel, 1991, Total Volatile Organic Concentrations in 2700 Personal, Indoor, and Outdoor Air Samples collected in the US EPA Team Studies. *Indoor Air, Vol. 1, No. 4* pp. 465-477.

L. Sheldon *et al.*, "Indoor Air Quality in Public Buildings, Volumes I and II," (EPA/600/6-88/009a, EPA/600/6-88/009b). August 1988. Available from National Technical Information Service, Springfield, VA 22161, (703) 487-4650.

L. Wallace, E. Pellizzari, E. Hartwell, V. Davis, L. Michael, and R. Whitmore, 1989, "The Influence of Personal Activities on Exposure to Volatile Organic Compounds." *Environment Research*, Volume 50, 37-55.

Emissions Testing

"FLEC" Available for Emissions Testing

As VOC emissions testing of indoor sources becomes more important, there is increasing recognition of the need to develop practical methods for collecting samples. Danish and Swedish researchers have developed and evaluated a small, portable device that can be used either in the field or in a laboratory setting. In Vol. 1, No. 4 of the *IAB*, we wrote about the new device being produced in Scandinavia called the Field and Laboratory Emission Cell (FLEC). The special virtue of the FLEC is that it can be used in two ways: to obtain very reliable emissions samples from surfaces in the field or as a test chamber in the laboratory. According to Peder Wolkoff, analytical chemist at the Danish National Institute of Occupational Health, it performs well in both contexts with reasonable replicability.

Wolkoff, a leading researcher on emissions testing from indoor sources, told us about a recent application of the FLEC. His group tested linoleum as part of an emergency investigation for a safety authority. Occupants had reported problems in a three-year old building with linoleum floor that had some water damaged areas. Wolkoff said he obtained excellent results, both qualitatively and quantitatively, with the FLEC comparing three linoleum samples: used, undamaged floor covering; the damaged linoleum; and, the original (unused) linoleum. He plans to present the results in a paper at Indoor Air '93 in Helsinki next summer.

Per Clausen, also of Denmark, presented a paper at the ASTM Indoor Air Modeling Symposium in Pittsburgh last April in which he described results of tests made with the FLEC. Emissions from vinyl floor covering were evaluated and the results appeared reliable.

The FLEC itself is a round, stainless steel chamber with carefully designed sample collection ports in the top. The top is placed over the material sample being tested, and the material becomes the bottom part of the cell. This design limits sample size; whatever goes in the device must be fairly thin. A researcher can only sample one surface, but the portability and short sampling time required make it an excellent field or laboratory test chamber.

The FLEC is now in production and is available from Chematec in Denmark. The manufacturer intends to produce some accessories and software for the device. The pre-production price was around U.S.$3,000. Contact Chematec for current pricing information.

For more information:

Contact Poul Erik Soerensen, Managing Director, Chematec Denmark, Dr. Sofies Vej 112, DK4000 Roskilde, Denmark. Tel. 45 42 36 28 80, Fax 45 42 36 33 30.

See *IAB*, Vol. 1, No. 4, (August 1991) for a more detailed description of the FLEC device itself.

Publications

Swedish Review of Material Emissions

Interest in VOC emissions from building materials has grown rapidly along with concern about IAQ. Many IAQ problems have been traced to sources that were part of the original construction. But the sources are diverse, the investigation methods are not standardized, and, until now, there has been no comprehensive review of the cases that have been reported in the published literature.

In *IAB* Vol. 1, No. 5, (September/October 1991) we discussed the findings of a study conducted by Hans Gustafsson, an analytical chemist at the Swedish National Testing and Research Institute. Now his complete report has been published. It contains considerably more detail than the paper he presented at ASHRAE's Healthy Buildings '91. The report is titled *Building Materials Identified as Major Sources for Indoor Air Pollutants: A Critical Review of Case Studies*.

The report will interest readers who investigate problem buildings as well as researchers and manufacturers who are interested in emissions from indoor sources. While the report is mostly a compilation of research reported by others, it is the first comprehensive survey of its kind. It provides both qualitative and quantitative data on the reported case studies. And, the diversity of case studies reported provides a broadly interesting set of examples. In all, Gustafsson reports 24 case studies which are mostly from northern Europe and North America.

After the case study presentations, Gustafsson presents a critical review and comments. One of his observations is that more chlorinated solvents are used in North America than in Europe. These solvents are used in paint solvents and similar products as well as in water and in dry cleaning products for clothes.

"Natural" Linseed Oil A Culprit

Typical of the comments we found interesting were those about linseed-oil-based products such as linoleum and paints. Linseed oil is favored by some who prefer natural rather than synthetic chemical based products. Gustafsson tells us that linseed oil's several high molecular carboxylic acids with double bonds do not always cross-bond during the main drying (hardening) process. Oxidation at the unreacted double bonds can result in aldehyde formation and, we presume, release into indoor air.

In one case, paint applied to a radiator released aldehydes with a range of molecular weights. Gustafsson hypothesizes that heat from the radiator accelerated oxidation of the aldehydes to odorous carboxylic acids.

Linseed oil in linoleum is hardened by storing the product at elevated temperatures for three to four weeks. Gustafsson writes, "...in several cases smell has nevertheless been noted from linoleum floor covering." One linoleum was releasing the aldehyde hexanal along with other substances. Gustafsson also suggests that heat can cause the formation of carboxylic acids in linoleum as well. In one reported case, the linoleum gave off a stronger odor when the sun was shining on it.

The use of strong detergent on linoleum can also result in emissions of strong odors. By damaging the surface layer, the detergent makes it easier for dirt and water to penetrate into the linoleum. The odor disappears fairly quickly, however. Gustafsson attributes the odor to the formation of fatty acids from alkaline hydrolysis of particles of fat and dirt in the binder.

Danish Energy Conservation Reduces VOCs

A study of low-energy Danish houses showed concentrations of total VOC being halved in less than six months. In one case, a gravel bed was being used for the storage of heat accumulated in the house exhaust air during the day. At night, incoming ventilation air passed through the gravel bed and presumably desorbed some of the pollutants that had collected during the day.

Moisture Problems

A Dutch investigation found damp mineral wool releasing aldehydes; this was probably a result of microbial growth. We recently heard of an office building in the US where a foul smell resulted in vacating an entire floor. The smell only occurred during humid weather. The investigators determined the smell came from ceiling tiles that the manufacturer had recognized as being from an unusual batch.

A large proportion of the cases reviewed by Gustafsson involved moisture even though, as he points out, only a small number of material emissions are affected by moisture. Most cases involved elevated emissions due to hydrolysis of plasticizer in floor covering material as a result of damp, alkaline concrete. This, we note, seems to be a problem especially in Sweden. It is attributed to incorrect design, insufficient drying of the concrete before installing floor coverings, or to not protecting concrete against precipitation.

Swedish Emissions Test Standards for Flooring Products

Gustafsson told *IAB* that a third of the case studies related to flooring materials. That is one reason the Swedish Flooring and Trades Association has established a trade standard for determining emissions of VOCs. The standard is based on the FLEC test chamber. (See the FLEC article on page //n of this issue). Swedish producers have tested over 80 various materials, and some have provided the TVOC values to architects and building contractors in a special form for emissions declarations. Emissions factors are given for materials aged for 4 and 26 weeks after unwrapping the newly produced material.

Similar trade standards have also been established for other materials such as paint, fillers for walls, floor topping compounds, and wallpaper. Gustafsson has promised to send these standards when they are translated, and we will discuss them in a future issue of the *IAB*.

The report concludes with a review of mitigation methods, research projects on emissions testing, and the development of low-emitting materials. There are over 120 references.

Reference:

Hans Gustafsson, 1992, *Building Materials Identified as Major Sources for Indoor Air Pollutants: A Critical Review of Case Studies. Hans Gustafsson. Swedish Council for Building Research. Document D10:1992. Available from Svensk Byggtjänst, S-171 88 Solna, Sweden. Approximate price: SEK 80.*

For more information:

Contact Dr. Hans Gustafsson, Swedish National Testing and Research Institute, P. O. Box 857, S-501 15 Borås, Sweden. Tel. 46 33 16 50 00, Fax 46 33 13 55 02.

NADCA Approves Performance Standard

The National Air Duct Cleaners Association (NADCA) has announced approval of its performance standard, "The Mechanical Cleaning of Non-Porous Air Conveyance System Components." The standard describes a method for quantifying particulate matter debris on non-porous surfaces in HVAC systems. A vacuum test is performed over a standardized area delineated by a template described by the standard. The cleanliness of the tested surface indicates the quality of the cleaning process. The NADCA Board of Directors approved the standard at its October meeting in Washington, D.C.

Now that NADCA has completed its easiest and its hardest task, we look forward to the development of more standards and guidelines for this growing IAQ maintenance industry.

I mention "easiest" because non-porous surfaces are neither as difficult to clean nor as controversial as porous surfaces such as fiberglass duct liners and sound attenuators commonly encountered in ductwork and terminal units. Some authorities simply recommend removing badly soiled or microbe-contaminated duct liners rather than trying to clean them. But there are firms offering cleaning services, and there should be standard methods for assessing the need for such services and the performance and impacts of the service when performed.

I mention "hardest" because the first project of this sort for a relatively new organization is always difficult. The NADCA standard went through several drafts and revisions over a two-year period before approval this fall. While the test is a useful one, it still does not tell us anything definitive about the quality of the air passing through and emerging from the tested components. Bud Offermann (Indoor Environmental Engineering, San Francisco) believes that the real test is the difference between the quality of the air upstream and downstream of the cleaned portion of the system.

The NADCA Standard is accompanied by "Guideline to NADCA Standard 1992-01" and a test template to be used with the vacuum test.

Copies of the standard are available through NADCA Headquarters, 1518 K Street, NW, Suite 503, Washington, DC 20005, (202) 737-2926, fax (202) 638-4833.

Calendar

Domestic Events

January 23-27, 1993. **ASHRAE Winter Meeting and International Air-Conditioning, Heating, and Refrigerating Exposition**, Palmer House, Chicago, Illinois. Contact ASHRAE Meetings Department, 1791 Tullie Circle NE, Atlanta, GA 30329, (404) 636-8400.

February 2-3, 1993. **IAQ Short Course for Building and Facility Managers**, Philadelphia, Pennsylvania. Presented by Mid-Atlantic Environmental Hygiene Resource Center, Sponsored by EPA Region 3 and US Public Health Service Division of Federal Occupational Health. Contact: Dr. Susan T. Smith, University City, 3624 Science Center, Philadelphia, PA 19104, (215) 387-2255.

February 7-10, 1993. **Dynamics of a Changing Industry**, 4th Annual Meeting and Exposition, National Air Duct Cleaners Association, Loews Anatole Hotel, Dallas, Texas. Contact NADCA, Headquarters, 1518 K Street, NW, Suite 503, Washington, DC 20005, (202) 737-2926, fax (202) 638-4833.

February 9-12, 1993. **Indoor Air Quality Symposium**, Georgia Tech Research Institute, Atlanta, Georgia. Contact GTRI, Training Programs Office, (404) 894-7430.

February 11-12, 1993. **Indoor Air Quality for Facility Managers**; IFMA Professional Development Course, Tempe, Arizona. Sponsored by International Facility Management Association (IFMA). Contact: Susan Biggs, IFMA, 1 East Greenway Plaza, 11th Floor, Houston, TX 77046-0194. (800) 359-4362, fax (713) 623-6124. *This is two-day overview of IAQ focuses on knowledge and skills needed by facility managers to prevent and solve IAQ problems. Instructor is IAB Editor Hal Levin. Enrollment is limited. Cost is $545 for IFMA Members and $595 for non-members prior to January 12. After that it goes up $50.*

March 18-19, 1993. **Workshop: Diagnosing and Mitigating Indoor Air Quality Problems**, Alexis Park Resort, Las Vegas, Nevada. Sponsored by Association of Energy Engineers (AEE). Contact: AEE, 4025 Pleasantdale Road, Suite 420, Atlanta, GA 30340, (404) 447-5083, fax (404) 446-3969. *Fee: AEE Member $695, Non-member $795.*

March 29-31, 1992. **Indoor Air Pollution**, Sixth Annual Conference, Adam's Mark Hotel, Tulsa, Oklahoma. Sponsored by University of Tulsa. Contact: Division of Continuing Education, 600 South College Avenue, Tulsa, OK, 74104-3189, fax (918) 631-2154.

April 21-23, 1993. **Indoor Environment '93, Indoor Pollution Conference and Exhibition.** Hyatt Regency On the Inner Harbor, Baltimore, Maryland. Sponsored by IAQ Publications, Inc. Contact Conference Director Lisa Markham, IAQ Publications, 4520 East-West Highway, Suite 610, Bethesda, MD 20814. (301) 913-0115, Fax (301) 913-0119.

May 3-7, 1993. **Air & Waste Management Association Annual Symposium**, "Measurement of Toxic and Related Air Pollutants," Omni Hotel and Convention Center, Raleigh, North Carolina. Contact Martha Swiss, A&WMA, P. O. Box 2861, Pittsburgh, PA 15230, (412) 232-3444, fax (412) 232-3450.

May 15-21, 1993. **American Industrial Hygiene Conference and Exposition**, New Orleans Convention Center, New Orleans, Louisiana. Contact: AIHA, 2700 Prosperity Avenue, Suite 250, Fairfax, VA 22031, (703) 849-8888, fax (703) 207-3561.

June 13-18, 1993. **New Summits for Environmental Solutions**, 86th Annual Meeting and Exhibition of the Air & Waste Management Association. Colorado Convention Center, Denver, Colorado. Contact: Marci Mazzei, A&WMA, PO Box 2861, Pittsburgh, PA 15230-9940, (412) 232-3444, fax (412) 232-3450. *Nearly 200 technical sessions including three major topics: waste, air (including indoor air), and environmental management. Three-day exhibition is "most comprehensive event of its kind held in North America in 1993." Advanced registration $375/$460 for members/others respectively.*

June 26-30, 1993. **ASHRAE Annual Meeting**, Radisson Hotel, Denver, Colorado. Contact: See listing above under January 23-27, 1993.

October 10-13, 1993. **Understanding the Workplace of Tomorrow**, 14th Annual Conference and Exposition on Facility Management, International Facility Managers Association (IFMA). Denver Convention Center, Denver, Colorado. Contact IFMA Headquarters, 1 East Greenway Plaza, 11th Floor, Houston, TX 77046-0194. (800) 359-4362. *A Call for Presentations has been issued, and the deadline is January 8, 1993. 150-word abstracts are due along with a completed application for presentation form.*

November 7-10, 1993. **IAQ '93: Operating and Maintaining Buildings for Health, Comfort and Productivity**, Philadelphia, Pennsylvania. Sponsored by ASHRAE. Contact: ASHRAE, see listing for Winter Meeting, January 23-27, 1993. *The press release states: "The symposium will focus on building system operation and maintenance practices, will bring together builders, designers, property managers and scientists to exchange experiences and solutions which provide acceptable indoor air quality." ASHRAE has assembled a long and impressive list of virtually all relevant organizations in the U.S. to participate in this practice-oriented conference. If the past two ASHRAE IAQ conferences are a reliable indication, this should be an outstanding conference.*

International Events

February 17-19, 1993. **Building Design, Technology & Occupant Well Being in Cold and Temperate Climates**, Palais des Congrès, Brussels, Belgium. Contact: ATIC-CDH, chausee d'Alsemberg 196, B-1180 Brussels, Belgium, . 32-2-348-05-50; Fax 32-2-343-98-42.

March 4-6, 1993. **Second Spanish and Interamerican Air Conditioning and Refrigeration Congress—CIAR '93**, Madrid, Spain. Contact CIAR '93, Parque Ferial Juan Carlos 1, 238067, Madrid, Spain, 722-50 00, fax 722 57 90.

July 4-8, 1993. **Sixth International Conference on Indoor Air Quality and Climate, Indoor Air '93**, Helsinki, Finland. For more information, a copy of the conference announcement, or the call for papers, contact the confeence secretary at: Indoor Air '93, P.O. Box 87, SF-02151 Espoo, Finland, fax +358-0-451-3611. *This most important indoor air conference is held every three years and is always a very exciting and rewarding event. Make plans now to attend this most important of international indoor air conferences. Recent devaluation of Finnish currency will help make this a more affordable conference to attend.*

October 27-28, 1993. **Volatile Organic Compounds**, Royal College of Physicians, London, England. Sponsored by Indoor Air International (IAI). Contact: Conference Secretariat, International VOC Conference, Unit 179, 2 Old Brompton Road, London SW7 3DQ, UK, +44 767 318 474, Fax +44 767 313 929.

November 1-3, 1993. **Clima 2000**, Queen Elizabeth Conference Centre, London, England. Contact: Anne Gibbins, CIBSE Headquarters, 222 Baltham High Road, London, SW 12 9BS, fax 44-1-6755449.

March 15 - 18, 1994. **Cold Climate HVAC '94 - International Conference on HVAC in Cold Climates**. City of Rovaniemi, Finland. Sponsored by FINVAC, Federation of Societies of Heating, Air Conditioning and Sanitary Engineers in Finland. Contact: FINVAC/Cold Climate HVAC '94, Mr. Ilpo Nousiainen, Sitratori 5, SF-00420 Helsinki, Finland, +358 0 563 3600, Fax +358 0 566 5093. *Abstracts are due March 1993; papers are due October 1993. The official conference language is English.*

Indoor Air BULLETIN

Hal Levin, Editor and Publisher
Subscription Manager: Gina Bendy
Editorial Office: 2548 Empire Grade, Santa Cruz, CA 95060; (408) 425-3946 FAX (408) 426-6522
Subscription Office: P.O. Box 8446 Santa Cruz, CA 95061-8446: (408) 426-6624 FAX (408) 426-6522

Subscriptions: $195 per year (12 issues) in the U.S., $235 per year (12 issues) outside the U.S.
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