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The total VOC levels were 29% lower after the bake-out than before. However, since the initial measurements were made shortly after completion of the installation of many finishes, we do not know whether the decrease was the result of the bake-out or the normal decay due to aging that might occur during the week between the measurements. And the levels were low to begin with, perhaps because the ventilation system was run during the installation period. Furthermore, we do not know whether this effect persisted or was transitory.

The investigators report that the bake-out procedure did demonstrate potential as a means to reduce VOC levels in new or renovated buildings. They suggest that since the decrease in levels after the bake-out was modest, it may be necessary to employ longer bake-out periods to achieve more significant effects.

A Word of Caution

Concerns have been raised about the possible negative consequences of the bake-out process. Damage could occur to HVAC components or to moisture-sensitive objects (such as art work, wood furnishings) or building components. IAQU welcomes your comments if you have had experience with bake outs.

For more information contact: John Girman, Indoor Air Quality Program, Air Industrial Hygiene Laboratory, California Department of Health Services, 2121 Berkeley Way, Berkeley, CA 94704; (415)540-2469.

Factors in Sick Building Syndrome: The Danish Town Hall Study

The causes of sick building syndrome (SBS) are elusive. Several hypotheses have been put forward, including the ideas that volatile organic compounds (VOC), microorganisms, thermal factors, psychosocial factors, institutional factors, and others are responsible individually or in combination.

A major study of SBS has been conducted by a team of Danish researchers. A study of 14 town halls in Greater Copenhagen confirmed work done elsewhere regarding SBS. While reported symptom levels were high for mucosal irritation (28%) and for general symptoms in the form of headache, abnormal fatigue, or malaise (36%), the measurements of environmental factors did not identify a single causal agent. However, clusters of factors were associated with higher rates of reported symptoms.

Results

The research team measured indoor climates in the 14 town halls. A questionnaire study and a clinical study of 4,369 employees in the town halls and 14 affiliated buildings were also conducted. While none of the measurements indicated the cause of the complaints, the very large range found for most variables (see Table 1) provided the basis for a multifactorial analysis, which led to these findings:

1. *Elevated rates of mucosal irritation were associated with the size of the allergenic fraction of floor dust, the length of open shelves per cubic meter of air, the area of fleecy material per cubic meter of air, the number of work stations, and air temperature.*

2. *Symptoms correlated strongly with job category, with the highest prevalence found in subordinate job categories. Jobs involving photoprinting, working at video display terminals, and handling carbonless paper correlated with the reported frequency of mucosal irritation and of general symptoms; the number of weekly working hours of women also correlated with reports of these two symptom categories, although less strongly.*

3. *As in several other studies, symptoms were more prevalent among women than men*

and they complained more frequently about indoor climate.

4 *Symptom prevalence rates varied significantly among buildings, supporting the notion that the symptoms are building-related. The lowest prevalence of symptoms was found in the oldest town halls (the buildings were mostly less than 30 years of age, with one almost 50 and another 80 years old).*

5 *The difference between mechanically and naturally ventilated buildings was not significant for this study. This is in sharp contrast to the results of a large-scale British study.*

These results have practical implications for controlling indoor air quality in problem buildings. These are described in "Practical Tips for Indoor Air Quality Control" on page 7 of this issue.

References

Peder Skov, Ole Valbjϕrn, and the Danish Indoor Climate Study Group. "The Sick Building Syndrome in the Office Environment: The Danish Town Hall Study." *Environment International,* Vol. 13, pp. 339-349, 1987.

Ole Valbjϕrn and Peder Skov. "Influence of Indoor Climate on the Sick Building Syndrome Prevalence" *Indoor Air '87; Proceedings of the 4th International Conference on Indoor Air Quality and Climate* (Vol. 2). Berlin, August 17-21, 1987. Berlin: Institute for Water, Soil and Air Hygiene. pp. 593-597.

Table 1: Indoor climate measurements in 14 Danish town halls (Valbjϕrn and Skov 1987).

		Mean	Minimum	Maximum
Mean external temperature	(24 hours)(°C)	2.4	-1.2	11.4
Average daily sunshine	hours	2.3	0	6.4
Air temperature	(°C)	22.7	20.5	24.1
Person-weighted air temperature	(°C)	23.0	22.0	24.4
Temperature rise during a work day	(°C)	2.5	1.0	8.0
Vertical temperature gradient	(°C/m)	0.9	0.4	2.0
Air velocity	(m/s)	0.15	<0.15	0.20
Relative humidity	(%)	32	25	40
CO_2	(%)	0.08	0.05	0.13
Formaldehyde	mg/m^3	0.04	0	0.08
Static Electricity: Observer	(kv)	1.4	0	4.8
Occupants max.	(kv)	1.7	0	4.0
Airborne dust	(mg/m^3)	0.201	0.086	0.382
Dust particles: >0.5 µm	(l^{-1})	48x10^3	19x10^3	119x10^3
>2.0 µm	(l^{-1})	25x10^2	8x10^2	116x10^2
Airborne microfungi	(col/m^3)	32	0	111
Airborne bacteria	(col/m^3)	574	120	2,100
Airborne actinomycetes	(col/m^3)	4	0	15
Vacuum cleaned dust[a]	(g/12m^2)	3.67	0.32	11.56
Vacuum cleaned dust[b]	(g/12m^2)	6.14	0.66	17.04
Macromolecular content in the dust	(mg/g)	1.53	0	5.24
Macrofungi in the dust[a]	(col/30 mg)	33	11	90
Macrofungi in the dust[b]	(col/30 mg)	32	6	192
Bacteria in the dust[a]	(col/30 mg)	199	41	380
Bacteria in the dust[b]	(col/30 mg)	296	160	680
Man-made mineral fibers in air MMMF	(f/m^3)	5	0	60
Not MMMF (<3 µm) in the air	(f/m^3)	33.2x10^3	18.5x10^3	59.1x10^3
Not MMMF (>3 µm) in the air	(f/m^3)	3.1x10^3	0.7x10^3	5.0x10^3
VOC (charcoal)[c]	(mg/m^3)	1.56	0.43	2.63
VOC (Tenax)[d]	(mg/m^3)	0.5	0.1	1.2
A-weighted equivalent noise level, $L_{A,eq}$	(dB)	56.7	51.3	60.3
A-weighted background noise level, L_{95}	(dB)	36.2	28.2	44.1
Reverberation time	(s)	0.41	0.28	1.05

Notes:
a = In the office where all the measurements were performed. b = In an office with a considerable loading of clients during the day.
c = Mean of readings in 6 buildings d = Mean of readings in 13 buildings, in one building measured 32 mg/m^3.

TOOLS & TECHNIQUES

Landmark Document on Residential IAQ from Canada

Health and Welfare Canada has published Exposure Guidelines for Residential Indoor Air Quality, prepared by the Federal Provincial Advisory Committee on Environmental and Occupational Health. This is a landmark document for Canada, and provides those interested in guidance with extremely useful information.

Published in April 1987, the guidelines divide contaminants into carcinogens and noncarcinogens. The health effects of many contaminants are described and recommended values are given for airborne concentrations (see Table 1). Noncarcinogens included are aldehydes, carbon dioxide, carbon monoxide, nitrogen dioxide, ozone, particulate matter <2.5 microns, sulphur dioxide, and water vapor. *The only listed carcinogen is formaldehyde.*

Several *additional substances* are identified for controlled exposures but *recommended levels are not provided.* They include biological agents,

Summary of Exposure Guidelines

Contaminant	Acceptable Exposure Ranges	
	Short-term	Long-term
Aldehydes (total)	$\Sigma c_i/C_i \leq 1$ [a]	—
Carbon Dioxide	—	≤6 300 mg/m³ (≤3 500 ppm)
Carbon Monoxide	≤11 ppm — 8 h [b] ≤25 ppm — 1 h [b]	— —
Formaldehyde	(c)	(d)
Nitrogen Dioxide	≤480 µg/m³ (≤0.25 ppm) — 1 h	≤100 µg/m³ (≤0.05 ppm)
Ozone	≤240 µg/m³ (≤0.12 ppm) — 1 h	—
Particulate Matter [e]	≤100 µg/m³ — 1 h	≤40 µg/m³
Sulpher Dioxide	≤1 000 µg/m³ (≤0.38 ppm) — 5m	≤50 µg/m³ (≤0.019 ppm)
Water Vapor	30-80% R.H. — summer 30-55% R.H. — winter [f]	— —

[a] C_i = 120 µg/m³ (formaldehyde); 50 µg/m³ (acrolein); 9,000 µg/m³ acetaldehyde), and c_i are respective concentrations measured over a 5 minute period.

[b] Units given only in parts per million so that guidelines are independant of ambient pressure.

[c] See Aldehydes (total).

[d] See page 26.

[e] ≤2.5 µm mass median aerodynamic diameter — MMMD.

[f] Unless constrained by window condensation.

Table 1
Landmark Document on Residential IAQ

Table 2 — Landmark Document on Residential IAQ: Summary of Exposure Control Recommendations

Contaminant	Recommendation
Biological Agents	In order to prevent many of the common indoor problems due to biological agents, measures should be taken to ensure that: • excess humidity and condensation are not present • surfaces are kept clear of dust • stagnant water sources, such as humidifier tanks, are kept clean and occasionally disinfected • a high standard of appropriate personal hygiene is maintained
Consumer Products (chlorinated hydrocarbons, pest control aerosols)	It is recommended that exposures resulting from the use of consumer products be kept to a minimum by ensuring adequate ventilation and observing any other precautionary measures described on the product label and in any accompanying information. Pesticides should be used only when absolutely necessary.
Fibrous Materials	Precautions should be taken to minimize inhalation of, and skin contact with mineral fibers during home renovations and installation operations. Materials and products containing fibers should be examined periodically for signs of deterioration. Advice should be sought before removing or damaging any materials thought to contain asbestos.
Lead	In order to minimize the exposure of people, and especially children to lead of airborne origin, it is recommended that surfaces which may be contaminated be cleaned frequently and that a high standard of overall cleanliness be maintained.
Polycyclic Aromatic Hydrocarbons (PAHs)	Exposure to PAHs indoors should be kept to a minimum by: • ensuring that combustion systems, for example wood- and coal-burning stoves, are properly installed and maintained and operated under conditions of satisfactory ventilation. • adhering to the guidelines and recommendations given in this document for particulate matter and tobacco smoke
Tobacco Smoke	In view of the carcinogenic properties of tobacco smoke, any exposure to tobacco smoke in indoor environments should be avoided.

pest control products, aerosol products, fibrous materials, lead, polyaromatic hydrocarbons (PAHs), and tobacco smoke. Discussions of health effects are presented, and recommendations for reducing exposures are described, although many of these are vague and not particularly useful (see Table 2).

Copies of the guidelines may be obtained from Communications Directorate, Department of National Health and Welfare, 5th Floor, Brooke Claxton Building, Ottawa, K1A OK9, Canada.

Practical Tips for Indoor Air Quality Control

We can derive some practical tips for problem buildings from the Danish Town Hall Study and IAQ Diagnostics articles (as well as the "bake-out" article) in this issue.

Causes of SBS

The results of the Danish Town Hall Study support the prevailing wisdom that high levels of "sick building syndrome" complaints cannot be linked to a *single* indoor environmental variable. Even where many measurements are made of many variables, they will not necessarily reveal "the cause" of the complaints. But this does not mean that the complaints are unrelated to occupancy of the building in question.

A *cluster* of factors will probably be associated with a complaint building. These may include the following:

- ♦ a large allergenic fraction of dust (or airborne particles)
- ♦ large "fleecy" surface area
- ♦ large ratio of open shelf area to building volume
- ♦ a large number of work stations
- ♦ elevated air temperature

Newer buildings are more likely to have problems than older ones.

Both "fleecy" material and large open shelf area mean large amounts of surface area. Thus, dust and volatile organic compound reservoirs may be large, and under certain conditions may result in elevated levels of detached dust or desorbed VOC. Higher temperature will also increase volatization of organic chemicals (this is clearly demonstrated by the bake-out research). It may, in certain types of ventilation systems (such as variable air volume), be accompanied by systematic reductions in ventilation.

Type of Ventilation System

The Danish study did not find a correlation of complaint levels with the type of ventilation system — mechanical or natural. Thus the ventilation system question, which has been raised elsewhere, remains open at this time. Other recent investigations, particularly by the Honeywell IAQ Diagnostics group, have found inadequate HVAC design capacities and equipment in every problem building. Engineering evaluation of system design and installation are likely to reveal deficiencies.

Ventilation System Deficiencies

In three-fourths of the buildings Honeywell IAQD investigated, inadequate supply air was found. Two-thirds had inadequate supply air distribution. Together, these problems indicate that occupied spaces simply are not getting enough outside air. This is easy to evaluate, and sometimes easy to remedy. Carbon dioxide measurements or tracer gas measurements can qualitatively and quantitatively verify these deficiencies.

Tips

Investigation of problem buildings or design of new buildings should include careful consideration of the conditions in the building. Particularly important are the following:

- ♦ The total amount of exposed surface area in occupied spaces. Use hard surface flooring and wall coverings, where practical, and limit open shelving.
- ♦ The scheduling and set points for operation of the HVAC system. Increase hours of operation after periods of non-operation such as weekends, or after periods of low outside air ventilation rates (warm weather), to remove accumulated VOC and particles.
- ♦ Supply air temperatures. Keep them as low as occupants will tolerate, to reduce VOC emissions, immediately prior to and during occupancy periods. During extreme weather periods, supply air should be cooler than room air to improve mixing within the space — warm supply air is more likely to stratify or short circuit.
- ♦ Outside air fraction and supply air distribution. Be certain that adequate outside air is supplied during the minimum flow conditions, usually extremely warm or cold weather. Verify that this air is reaching occupants by using tracer gases (carbon dioxide will work at levels far below toxicity).
- ♦ The quality of housekeeping related to dust control on floor, wall, and storage-shelf surfaces. Use and properly maintain high-efficiency filters (>70% ASHRAE dust spot rating).

FEATURE

IAQ Diagnostics for Problem Buildings

With growing recognition of indoor air quality problems in buildings, the opportunities for engineering and other consulting firms to provide services have increased rapidly in recent years. New firms have been established and older firms have expanded their capability and their marketing to capture some of the growing market.

One of the beacons in the IAQ field is James E. Woods, Jr., a former professor of mechanical engineering, who now directs a multidisciplinary team of engineers and scientists at Honeywell Indoor Air Diagnostics in Golden Valley, Minnesota. Woods chaired the ASHRAE committee that developed Standard 62-1981 and served on the National Academy of Sciences Committee on Indoor Pollutants. His current efforts are applying his broad knowledge and experience to resolving air quality problems in buildings.

In this article we will first present Honeywell's data on the causes of air quality problems in buildings. Woods presented this information while testifying before a U.S. Senate subcommittee hearing last fall on Sen. George Mitchell's indoor air quality bill (see page 1 of this issue). This is followed by a description of a practical, systematic approach to diagnosing these problems, which was developed by Woods and his colleagues at Honeywell.

Causes of IAQ Problems

According to Honeywell IAQ Diagnostics (IAQD) data summarizing 30 recent cases, 65% of IAQ problems in buildings investigated were diagnosed as "sick building syndrome" (SBS), and 35% were diagnosed as both SBS and "building related illness" (BRI). While SBS and BRI share many of the same flu-like symptoms, BRI is defined as a clinically verifiable disease entity (such as hypersensitivity pneumonitis, Pontiac fever, Legionnaire's disease, or allergic dermatitis) while SBS is diagnosed when complaints and symptoms are clearly associated with occupancy of the building but no causal agent can be positively identified.

Chemical contamination was found in 75% of Honeywell's reported investigations, with 55% having thermal problems, 30% humidity problems, and 45% microbiological contamination. Of the chemical contaminants, odors were detected in 70% of the cases, particulate matter (in excess of 50 $\mu g/m^3$) in 5%, and other chemicals in 5%.