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COMPREHENSIVE EVALUATION OF MATERIALS

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This paper discusses the evaluation of indoor air quality impacts on materials used in buildings. The types of evaluations discussed will be of use to specifiers, such as architects, builders, or building owners; manufacturers; and standards organizations in both the private and government sectors. Most of what is said about evaluation of new or prospective materials also applies to the evaluation of materials from buildings with indoor air quality problems.

The paper has three parts. In the first part, I briefly discuss some of the causes of indoor air quality (IAQ) problems. The second part deals with evaluation of indoor materials in a conceptual way, then discusses the state of the technology for evaluating potential IAQ problems. The last part presents my view of how materials can be comprehensively evaluated for IAQ concerns. The key to this comprehensive evaluation will be the determination of probable health and comfort effects of the emissions from those materials.

Causes of IAQ Problems

IAQ problems occur in buildings either because the ventilation is inadequate or because there are unusually strong sources of indoor air contaminants. Ventilation can be inadequate because of design or operation; insufficient quantity or quality of outdoor air; ineffective distribution of ventilation air inside the building; or ineffective exhausting of air from the building. Unusually strong sources of air contaminants can either be building materials or material contents of the building; activities of people or machines in the building; operation of combustion devices; or contaminated outdoor air that is introduced into the building.

Material sources, the source type of particular interest in this presentation, comprise the following:

- Building materials
    - floor, wall, and ceiling materials
    - adhesives, sealants, coatings
- Furnishings
    - furniture, fabrics
- Consumable products
    - cleaners, solvents, treated paper products
- Office machines
- Ventilation system components

Comprehensive Evaluation of Materials

A truly comprehensive evaluation of materials used in buildings would, of course, go beyond indoor air quality concerns. The properties that influence selection of appropriate materials for buildings include those listed in Table 1. To be completely desirable, materials have to satisfy a wide range of requirements. Desirable aspects of the properties listed in Table 1, with particular emphasis on IAQ concerns, are listed in Table 2. From this point, I will discuss evaluation in a less comprehensive manner and will emphasize the evaluation of emissions properties of materials, since these are the properties that have the greatest impact on IAQ.

Comprehensive IAQ Evaluation of Materials

Today's state of technology for IAQ evaluation of materials has three basic steps:

- *Chamber studies of emissions.* These laboratory studies can evaluate emissions of chemical compounds, physical aspects of aerosols or fibrous particles, or microbials such as fungi and bacteria. Microbial emissions evaluations are seldom conducted, but more will be made in the future.
- *Mathematical modeling of the dispersion of the emitted substances.* This is done to estimate the indoor air concentrations of contaminants that result from the sources. Some of the existing mathematical models allow estimation of inhalation exposures by building occupants, given various time-activity patterns.
- *Comparison of estimated indoor concentrations and inhalation exposures to available toxicological data.* Available data are generally limited to standards that have been developed for out-door air and to occupational health and safety standards that have been developed for industrial workplaces. In both cases, these data have been developed for single compounds.

TABLE 1
Properties Influencing Selection

Physical	Strength Durability Heat transmission Light transmission Maintainability Effectiveness (e.g., as a cleaning agent)
Aesthetic	Color Texture Odor Noise
Economic	Initial cost Maintenance cost Operating cost (e.g., energy)
Environmental	Emissions to air Other releases Support of microbial growths Life-cycle impacts

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TABLE 2
Desirable Properties

Emission properties	Low emission rate Low toxicity of emissions
"Sink" properties	Non-sorbent If sorbent, not re-emitting If no re-emitting, non-nutrient
Microbial properties	Hydrophobic Non-nutrient Cleanable
Physical properties	As needed for the application
Aesthetic properties	As needed for the application
Cost	Reasonable

TABLE 3
Health and Comfort Effects/Symptoms

Irritation	of eyes, nose, upper airways, throat, skin
Odors	
Decreases in respiratory function	wheezing, cough, chest tightness, shortness of breath
Neurological symptoms	nausea, dizziness, headache, loss of coordination, tiredness, loss of concentration
Immunological reactions	inflammatory reactions (delayed and immediate/allergic)
Asthma	(aggravation of)
Cancer	
Respiratory infections	
Increased susceptibility	to infections or to chemical substances

Figure 1 shows this testing procedure diagrammatically. Decisions on selection of materials using this procedure are based on exposures to emissions. Basically, the lower the exposure the better, but especially noxious compounds need to be considered regardless of their concentrations. This procedure represents the current state of technology and if conducted properly is a good one, but the question remains as to whether there could be something better.

The current technology for emissions testing is inadequate for a number of reasons. First of all, the emissions are almost always complex mixtures of contaminants, and very little is known about the toxicity of mixtures. Furthermore, not all emissions mixtures are equal, toxicologically. Therefore, low exposures do not necessarily lead to low health effects. So the question is: How do we do better?

In my opinion, the answer lies in some approach that makes combined use of the knowledge of engineers, chemists, and biological and medical scientists. Development of biologically based methods is needed to improve methods of material evaluation. Table 3 is a general look at the type of effects that will need to be addressed. It is a tabulation of effects or symptoms that have been reported in the IAQ literature. Materials-testing schemes that attempt to get a more direct measure of health and comfort effects will need to address the kinds of effects and symptoms listed in that table.

The basic approach to evaluating materials for the effects can be much the same as the chemically and physically based approach illustrated in Figure 1. Figure 2 shows an approach where evaluations, in addition to having chemical and physical analysis, involve exposure chambers where bioresponse testing using humans or animals or *in vitro* assays are done. These have the potential of giving a more direct measure or prediction of human response. Although Figure 2 shows parallel testing by chemical analysis and bioresponse testing, the parallel testing would not always be necessary. In some instances, one or the other would be appropriate by itself.

Relatively few bioresponse methods are in a sufficient stage of development that they have very much prospect of being used for material evaluations in the near term. Five possibilities of such methods are listed in Table 4. The odor test panels would be relatively simple "sniff" tests where one or two sniffs of emissions from a material would be made by human panels. These would give an indication not only of odor but in some cases immediate irritation to the mucous membranes.

Longer-term irritation of airways might be measured by a test that is based on respiratory frequency change in mice. This is a test that is an ASTM standard. Another type of test for airway irritation would be to look at the inflammation of mucous membranes in the upper airways. This can be done by washing fluids from the nasal cavities of either people or animals and analyzing for polymorphonuclear neutrophils (PMNs).

PMNs, which are cells that indicate an inflammation response, can also be examined in the tear fluid of the eyes to get a measure of eye irritation. Since PMNs are relatively time-consuming and expensive to analyze, other markers of inflammation that are easier and less expensive to measure might someday be found for tests of mucous membrane and eye irritation. The final type of method listed in Table 4 deals with electrical potentials that are evoked in either the central nervous system or peripheral nervous system when a person or animal is exposed to a stimulus such as breathing air contaminants.

The types of methods listed above are certainly not inclusive; they are simply potential methods for evaluating materials.

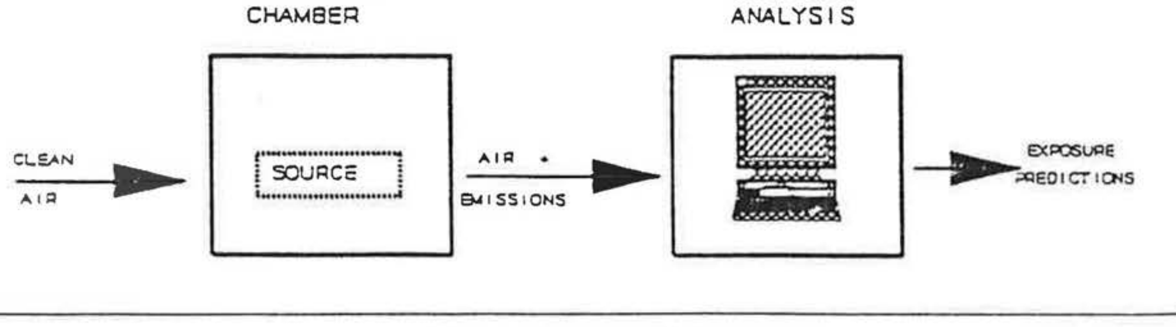

Figure 1 Evaluation of Emissions

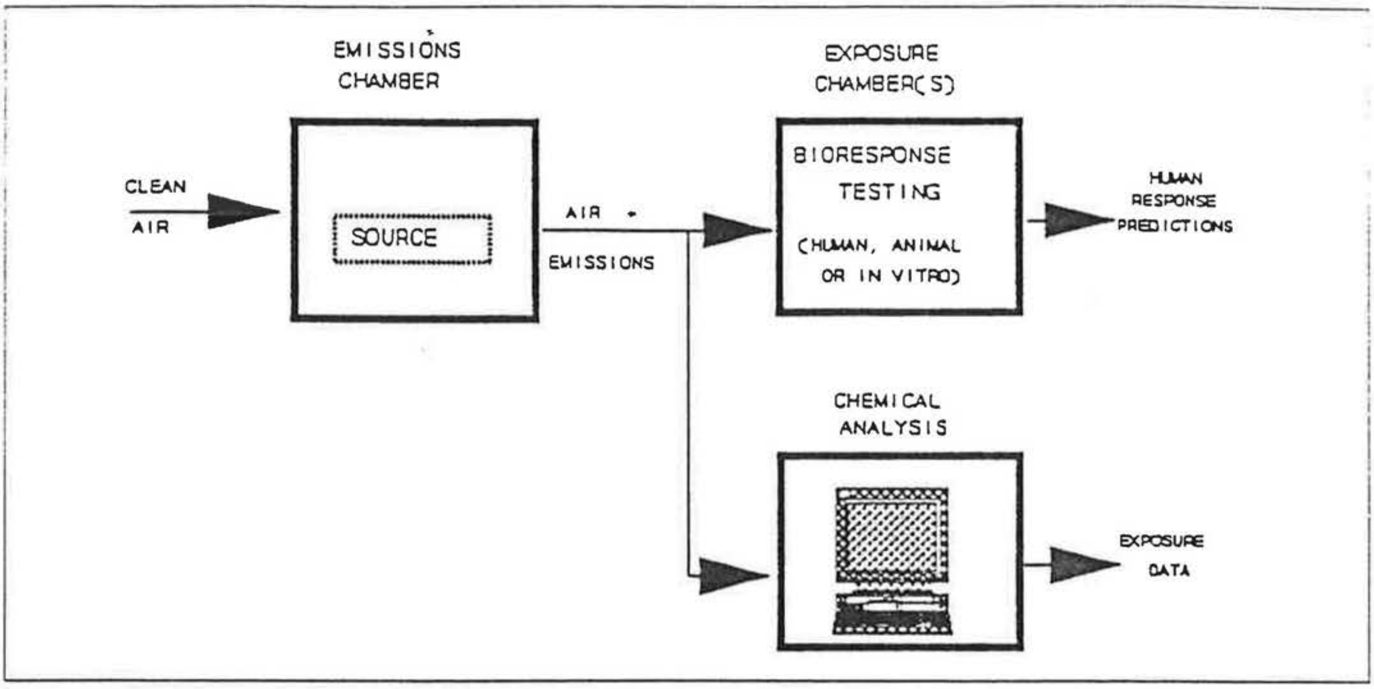

Figure 2 Evaluation of Effects

TABLE 4
Examples of Bioresponse Methods

Method	Effect/Symptom	Responder
Test panels	Odor/immediate irritation	Humans
Respiratory frequency change	Airway irritation	Mice
Mucous membrane inflammation	Airway irritation	Humans, animals
PMNs (e.g.) in tear fluid	Eye irritation	Humans, animals
Evoked potentials	Nervous system effects	Animals, humans

There is no doubt that some of them will not be feasible, and there are undoubtedly other methods that will be identified and developed in the years to come.

In summary, I would like to make the following points:

- Many IAQ problems are caused by unnecessarily strong sources of emissions of chemical, physical, and microbial contaminants.
- Methods for evaluating emissions rates and the compositions of those emissions are reasonably well developed.
- Methods for predicting emission dispersion and inhalation exposures are reasonably well advanced but further development is needed.
- Methods for directly evaluating the health effects of emissions are needed. We need to get closer to the bottom line (i.e., health effects) with our material testing methods.
- Bioresponse methods have potential for improving our prediction of health effects.