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DESIGN FOR MULTIPLE INDOOR ENVIRONMENTAL FACTORS

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ABSTRACT

Design of indoor environments should minimize occupant discomfort, irritation, and illness. Sick building syndrome symptoms, discomfort, and irritation can result from non-indoor air quality environmental factors such as noise, poor quality or inadequate lighting, lack of individual privacy or control, and other environmental factors. Interactions among the environmental factors and human responses to them are important considerations although they are complex and inadequately understood. A few examples clearly demonstrate their importance. Selection of design criteria should reflect consideration of these complex interactions. More research is necessary to inform design for indoor environmental quality.

INTRODUCTION

Design for good indoor air quality aims to prevent occupant discomfort, irritation, and illness. Sick building syndrome symptoms, discomfort and irritation can easily be the result of other non-indoor air quality environmental variables. There is evidence that many such symptoms or complaints are the result of noise, poor quality or inadequate lighting, lack of privacy or control, and other environmental factors that can cause these symptoms and complaints. When one or more of these factors is at values near or outside accepted guidelines or limits, the likelihood of an occupant becoming uncomfortable, irritated, or ill increases. Therefore, it is important to identify all critical environmental variables, to establish relationships between them, and to make indoor air quality related design decisions with full cognizance of the interdependent, dynamic relationships between indoor environmental variables.

An illustrative case is that of acoustic control where "fleecy" materials are often chosen for interiors and for mechanical ventilation system linings in conflict with the "ideal" indoor air quality solution of hard, durable, non-porous surface materials. Solutions to the acoustic problem must consider the IAQ implications, and the IAQ solutions must consider the acoustic implications if designs are to produce satisfied occupants. Similar considerations involve the selection and use of cleaning products and procedures, illumination, provision of access to operable windows and views, among many others. An effective design integrates indoor air quality concerns into a complete design program.

Although there may be some overlap among factors, they can be placed in four broad categories: (1). These factors are 1) Chemical, 2) Physical, 3) Biological, and 4) Psychological. Each category listed above has many sub-categories and many examples can be found in each of these of interactions (combined effects) with important environmental and personal factors (1). Many authors identify social and institutional factors separately from psychological factors (2). The psychological factors can be broken down into perception of the environment, perception of the environmental impact on occupants, experience of the environment conditions, and experience of the effects of environmental factors (3, 4). Social and institutional factors mediate human responses through psychological mechanisms -

psycho-physical and perceptual/experiential (4). A more detailed listing of the important factors in the indoor environment is provided in Table 1.

Table 1. Environmental factors to which the body responds

CHEMICAL	
	Organic gases and vapors
	Inorganic gases and vapors
PHYSICAL	
	Thermal factors: (Temperature, Air velocity, Radiant asymmetry)
	Moisture
	Electromagnetic energy (Visible light, Ultraviolet light, Infrared radiation, Cosmic radiation, Extremely low frequency, and Ionizing radiation)
	Electrostatic fields
	Mechanical energy (Noise and Vibration)
BIOLOGICAL	
	Types of organisms: (Viruses, Bacteria, Fungi, Arthropods, etc.)
	Status: (Viable or Non-viable)
	Effects: (Infectious agents, Allergens, Odorants, Asthmagenics)
PSYCHOLOGICAL	
	Emotion: (Anxiety, Fear, Anger, Fright, etc.)
	Perception (Environment, Effect of Environment, Personal-response)
	Processes: (Vision, Hearing, Odor Perception, Touch, Irritation, Itching)

The human body integrates its responses to all the environmental factors to which it is exposed: In addition to the environmental factors, personal factors can affect both the environmental impacts on the body and the occupant response. For example, clothing affects the convective, conductive, and radiant heat transfer thereby affecting thermal comfort. Metabolic rate affects thermal balance and comfort. The human body's response to the total environment is an integrated one (5, 6).. There are several possible outcomes of multiple exposures due to the human response to the interactions among the exposures or among the responses. The combined effect of these exposures may be an enhancement, diminution, or no effects depending on the combination. The result of interactions include the following:

- Independent: no interaction.
- Antagonistic: one counteracts the other.
- Prophylactic: one protects against the effect of another.
- Cumulative: over time, additive.
- Additive: they act as though independent but obtain their separate effects.
- Synergistic: effect of interaction is greater than additive.

Criteria for Achieving Acceptable Indoor Environments

The criteria recommended in most standards and guidelines for indoor environmental design values are derived from laboratory and field studies that typically evaluate only a small sub-set of environmental conditions. Very little research has been done to investigate the impacts of the full range of environmental variables on occupant satisfaction, and such investigations are extremely complex and costly. Therefore, the recommended criteria are necessarily limited by the availability of reliable data. However, the building designer must address important interactions among environmental variables that are likely to affect overall occupant comfort, health, and well-being. The user of indoor environmental guidelines should avoid assuming that meeting each separate criterion or separate sets of criteria will result in the satisfaction level achieved when only one variable or set of variables is addressed. (9)

EXAMPLES OF INTERACTIONS

Examples of interactions among environmental factors can be seen in the effects of many common medications, coffee, tobacco, alcohol, or so-called recreational drugs. It is common knowledge that certain prescribed medicines should not be taken together because of their combined effects. It is not commonly recognized that environmental factors combine with each other or with other factors affecting the human responses to them. Few of the potentially infinite combinations of interactions are adequately understood or even identified. No brief review can possibly cover all the known interactions of importance. The following examples of interactions among environmental factors and human responses to them indicate the range of combined effects or interactions that influence human responses to environmental conditions.

Temperature, Humidity, and IAQ Effects on Perceived Indoor Air Quality

Berglund and Cain (10) investigated the effect on perceived air quality (freshness, stuffiness, and acceptability) of 20 subjects at 1, 2 and 3 met and at 2°, 11°, and 20°C dew point temperatures at air temperatures of 20, 24, and 27 °C while holding air quality constant. Their results indicate that subjective comfort depends "…upon almost all perceptible influences." Temperature and humidity influenced not only thermal comfort but also "perception of the chemical quality of the air." Contaminant concentrations influenced subjective judgments of air quality, "…but in some instances, may actually prove secondary to temperature and humidity." Changes of 1.0°C "…had about the same effect on perceived air quality as changes of 3.36°C in dew point temperature. T>±26°C produced significant decrements in perceived IAQ

Interactions Between VOCs and Temperature

Mølhave and his co-authors (11) reported that human reactions to volatile organic chemicals (VOCs) at constant concentrations are greater at higher temperatures. They compared reactions to 0 and 10 mg/m^3 concentrations of a standard mixture of 22 VOCs at temperatures of 18, 22, and 26°C. They found nasal cross-sectional volumes decreased with decreasing temperature and increasing VOC exposure. Interactions were found for odor intensity, perceived facial skin temperature and dryness, general well-being, tear film stability, and nasal cavity dimensions. The authors concluded that the presence of interactions means future guidelines for acceptable VOC concentrations should depend on room air temperature. This finding is consistent with the reported by Berglund and Cain discussed above (10).

Temperature and Humidity Effects on Comfort, Productivity

Wyon reports from numerous separate studies he conducted or reviewed that many effects of thermal conditions on comfort and productivity. For example, moderate cold can reduce manual speed, sensitivity, and dexterity by up to 20%. Moderate heat can reduce reading speed, typewriting, and the kind of logical thinking required for mathematics by up to 30% in comparison with individual thermo-neutrality. Over an extended period of time, people do about 30% less work at 24°C than at 20°C. Drivers are less vigilant for signs of danger at 27°C than at 21°C. After 0.5 h they miss twice as many danger signs at the higher temperature (12).

Environmental Carcinogens: Modifying Effect of Co-Carcinogens on Response
A non-toxic substance can greatly potentiate the carcinogenic effects of a known carcinogen (13). Bingham and Falk (14) reported that cutaneous tumorigenesis in mice is accelerated 1,000-fold by the enhancement of potency at low concentrations of benzo[a]pyrene and benz[a]anthracene when n-dodecane is the diluent. They reported that the effect was most obvious during exposure to low concentrations of the carcinogen.

Formaldehyde Effects on Visual Sensitivity
In studies involving only 3 subjects, Melkhina (15) found an exposure threshold of 0.084 mg/m^3 formaldehyde (HCHO) for increased optical chronaxy (an indicator of nerve tissue irritability - heightened physiological responsiveness) and a threshold of 0.2 mg/m^3 HCHO for increased sensitivity to light. Investigators have often reported 0.08 mg/m^3 HCHO in new non-residential buildings, although recently less frequently than a decade ago due to reduced source strengths. The mean 1-week HCHO concentration in a random survey of mobile homes and manufactured housing conducted by the California Department of Health Services was 0.07-.09 ppm (0.08 - 0.1 mg/m^3) and was independent of the age of the mobile home (16) suggesting that older homes' stronger sources aged to about the strength of newer ones. Where bright light may be present but without causing problems in the absence of HCHO , it is plausible that the light will cause discomfort glare or other (temporary) visual interference.

Formaldehdye and Other Indoor Air Pollutants: The Case for a Synergistic Effect
Concentrations of HCHO and VOCs not known to cause irritation and other SBS complaints alone cause such complaints when present together. More than 80% of the most common indoor air pollutants identified in buildings and in material emissions were classified by Mølhave as mucous membrane irritants (17). This could be explained if some compounds act synergistically, and it appears somewhat plausible if they act in a roughly additive fashion.

Low Humidity and Particulate Matter Air Contamination
As humidity decreases, so does upper respiratory moisture and mucociliary removal action. Particles then may penetrate deeper and stay longer resulting in increased health effects for a given particle concentration. The irritation and discomfort of "dry nose," "dry throat," "itchy nose," "scratchy throat," as well as effects on other mucous membrane-protected surfaces (such as the eye) are plausibly exacerbated by low humidity (12) or other factors (18).

VDT Work and Indoor Air Pollution
Schneider et al (19) measured particle deposition velocities on a mannequin and modeled factors determining particle deposition velocities. They concluded that particle deposition velocities on operator facial skin and eyes may be increased up to ten-fold by electrostatic fields and air currents from visual display terminals (VDT). The weaker the air currents, the greater the influence of the electrostatic fields. The electrical field influences are greatest, according to the model, for particles near 1 µm; air currents are most important for particles near 10 µm. The results are important for assessing the contribution of particles to "office eye syndrome" attributed to particles and particle-bound surfactants in office environments. They could be important for skin and upper respiratory symptoms as well.

SBS - "Combined Effect" Syndrome?
Authorities agree that SBS etiology is usually multi-factorial (18, 20, 21). The combinations of implicated causal factors are too numerous to analyze effectively, and there is insufficient

data to do so in most cases anyway. The multitude of effects considered part of the syndrome are likely to have diverse and overlapping causes, thus producing many associations without necessary causal linkages. The Danish town hall study found clusters of causal factors that plausibly act in concert to produce higher symptom prevalence (21).

VOCs and Odor, Irritation Responses

Cometto-Muñiz and Cain (22) have studied human odor perception and irritation responses to a few homologous series of VOCs. They found that increasing the number of compounds in a complex mixture lowers the thresholds for odor and for eye and nasal irritation. In fact, they reported that increasing complexity and lipophilicity of mixtures increased additive effects. Eye irritation showed synergistic effects for the most lipophilic substance tested in a mixture of six components. They concluded that mixtures of chemicals cause human responses even when the individual chemicals are at concentrations far below their individual thresholds.

DISCUSSION AND CONCLUSION

Clearly interactions are important and they give rise to many questions for designers. What are the major combined effects of greatest concern in indoor air quality and climate work? What are the most important variables apart from the building environment that affect occupant reactions to the indoor environment? What are the most important variables to control in buildings to minimize adverse occupant reactions to combined effects? Given present knowledge of the numerous, potentially-significant interactions and combined effects, can we ignore or adequately address them in design, construction, and operation of buildings?

Selection of design criteria should reflect consideration of the complex interactions among indoor environmental factors and occupant responses to them. More research is necessary to provide clear design guidance for indoor environmental quality. Prudence suggests that environmental factors be controlled closely or by individual occupants to achieve acceptability.

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