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INTEGRATED DESIGN FOR TOTAL INDOOR ENVIRONMENTAL QUALITY

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Design for good indoor air quality IAQ) aims to prevent occupant discomfort, irritation, and illness. Sick building syndrome symptoms, discomfort and irritation can easily be the result of other, non-IAQ environmental variables. There is evidence that many such symptoms or complaints result from noise, poor lighting, lack of privacy or control, and other environmental factors that can cause these symptoms and complaints. It is important to identify the other critical environmental variables, to recognize relationships between them, and to make indoor environmental design decisions with full cognizance of the interdependent, dynamic relationships between all indoor environmental variables.. ASHRAE Guideline Project Committee 10P is developing "Criteria for Achieving Acceptable Indoor Environments," a document that will assist designers consider the total indoor environment.

INTRODUCTION

The body responds to all the factors in the environment to which it is exposed: Although there may be some overlap between and among factors, the factors can be placed in four broad categories listed in Table 1:

Table 1. Broad categories of factors affecting human health and well-being in the indoor environment (1)

- Chemical
- Physical
- Biological

Each of the categories listed in Table 1 has many sub-categories and many examples can be found in each of these of interactions (combined effects) with important environmental and personal factors. (Hinkle and Loring, 1977). Many authors identify social and institutional factors separately from psychological factors (Baker, 1989). The psychological factors can 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 (2; 3). Psychological factors modify the effects of environmental factors on occupant response. Social and institutional factors mediate human responses through psychological mechanisms - psycho-physical and perceptual - experiential.

A more detailed listing of the important factors in the indoor environment is provided in Table 2. Modifying factors are listed in Table 3.

In addition to the environmental factors, personal factors can affect both the way the environment affects the body and the way that effect is perceived. For example, clothing affects the impact of convective, conductive, and radiant heat transfer thereby affecting thermal comfort. Metabolic rate affects thermal balance and comfort.

Table 2. Environmental factors to which the body responds

CHEMICAL		
	Organic gases and vapors	
		Solvents
		Plastics
		Pesticides
		Fire retardants
		Human and other animal metabolites
	Inorganic gases and vapors	
		Combustion products
		Soil particles
		Atmospheric constituents
PHYSICAL		
	Thermal factors:	
		Temperature, Air velocity, Radiant asymmetry
	Moisture	
	Electromagnetic energy	
		Visible light
		Ultraviolet light
		Infrared radiation
		Cosmic radiation
		Extremely low frequency
		Ionizing radiation
	Electrostatic fields	
	Mechanical energy	
		Noise
		Vibration
BIOLOGICAL		
	Types of organisms	
		Virus, Bacteria, Fungi
	Status	
		Viable or Non-viable
	Effects	
		Infectious agents, Allergens, Odorants, Asthmagenics

Table 3. Psychological Factors the Modify the Effects of the Environment on Occupant Responses

Emotion:	
	Anxiety, Fear, Anger, Fright
Perception	
	Perceived hazard versus "real" hazard
	Perception of environment
	Perception of self/ perception of reactions to the environment
	Perception of self reacting to environment
Processes: Vision, Hearing, Odor, Touch, Irritation, Itching	

The body's response to its total environment is an integrated one (Selye, Strand, 1983).. There are several possible outcomes of multiple exposures due to the body's 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. They include but are not limited to 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

ASHRAE Guideline Project Committee 10P (GPC 10P), "Criteria for Achieving Acceptable Indoor Environments," was established following discussions at several ASHRAE meetings addressing concerns that there were conflicts and gaps between the requirements of ASHRAE Standard 62 (Ventilation for Acceptable Indoor Air Quality) and Standard 55 (Thermal Environmental Conditions for Human Occupancy) (6, 7). These concerns were focused primarily on the impact of the environmental conditions specified in the two standards on each other.

The scope of the GPC10P was broadened to include other indoor environmental factors that would affect occupant health, comfort, and well-being. These impacts on occupants are generally evaluated in ASHRAE standards by the "acceptability" of the indoor environment to the occupants or the percent of occupants that express dissatisfaction with the environment. It is intuitively apparent that if the criteria for each environmental factor or specific set of factors (air quality, thermal, lighting, noise, etc.) are established to achieve a given rate of satisfaction (typically 80%) in the building occupant population, then an indoor environment that just barely meets each criterion will not result in an overall satisfaction rate of 80% but likely will satisfy a far lower proportion of the occupants.

The criteria recommended in most standards and guidelines are derived from laboratory and field studies that often evaluate only a 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 guideline committee is identifying important interactions among environmental variables that are likely to affect overall occupant comfort, health, and well-being. The user of indoor environmental guidelines should be cautious in assuming that simply meeting each criterion or separate sets of criteria will result in the satisfaction level achieved when only one variable or set of variables is addressed. (8)

EXAMPLES OF INTERACTIONS AMONG FACTORS AND AMONG EVOKED HUMAN RESPONSES

Examples of interactions among environmental factors can be easily found by looking at the effects of many common forms of medication, or even coffee, tobacco, or so-called recreational drugs. It is common knowledge that certain drugs should not be taken together because of their combined effects. It is less common knowledge that environmental factors can combine with each other or with other factors affecting the human responses to them.

No brief review can possibly cover all the known interactions of importance. Few of the potentially infinite combinations of interactions are adequately understood or even identified. Following are several examples of interactions among a variety of environmental factors and human responses to them. These examples have been selected to attempt to convey a sense of 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 (9) 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 indicated that building occupant comfort depends "...upon almost all perceptible influences." They found that temperature and humidity influence 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 reported that human reactions to Volatile organic chemicals (VOCs) at constant concentrations are greater at higher temperatures. He compared reactions to 0 and 10 mg/m^3 concentrations of a standard mixture of 22 VOCs and temperatures of 18, 22, and 26°C. He 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 VOCs indoor air concentrations should depend on room air temperature. This finding is consistent with the reported by Berglund and Cain discussed previously. (10)

Temperature and humidity effects on comfort, productivity

Wyon reports from numerous separate studies he has conducted or reviewed, 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 30 minutes they miss twice as many signs of danger at the higher temperature (11).

Environmental carcinogens: modifying effect of co-carcinogens on the threshold response

A non-toxic substance can greatly potentiate the carcinogenic effects of a known carcinogen (National Research Council, 1975). Bingham and Falk (1969) 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. The carcinogens used were polycyclic aromatic hydrocarbons and the co-carcinogens (accelerators) with long- aliphatic chains possessing industrial or environmental significance. They reported that the effect was most obvious during exposure to low concentrations of the carcinogen. (12)

Formaldehyde effects on visual sensitivity

In studies involving only 3 subjects, Melkhina (13) found an exposure threshold of 0.084 mg/m^3 formaldehyde for increased optical chronaxy (an indicator of nerve tissue irritability - heightened physiological responsiveness) and a threshold of 0.2 mg/m^3 formaldehyde for increased sensitivity to light. Investigators have reported 0.08 mg/m^3 formaldehyde in new buildings, although less frequently than a decade ago due to reduced source strengths. The mean formaldehyde concentration in a random survey of mobile homes and manufactured housing conducted by the California department of health services was 0.088 ppb or ... Where bright light may be present but without causing problems in the absence of formaldehyde, it is plausible that the light will cause discomfort glare or other (temporary) visual debilitation or impairment.

Formaldehdye and other indoor air pollutants: the case for a synergistic effect

Concentrations of formaldehyde 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 as mucous membrane irritants (14). This could be explained easily if some of these compounds act synergistically and 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. Thus, particles may penetrate deeper and stay longer resulting in increased health effects for a given particle concentration. (Ib Anderson et al, 1979?). It is plausible that 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 exacerbated by low humidity. (11; 15)

VDT work and indoor air pollution

Research included measurements of particle deposition velocities on a mannequin and modeling of factors determining deposition velocities. The researchers 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 (16).

SBS - "combined effect" syndrome?

Authorities agree that SBS is multi-factorial (17). 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 showed clusters of causal factors that plausibly act in concert to produce higher symptom prevalences (18).

VOCs and Odor, Irritation Responses

Cometto-Muñiz and Cain (19) 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

There are a number of questions that need to be answered. 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 the enormous number of potentially significant combined effects, how can we ignore (or adequately consider) them in design, construction, and operation of buildings?

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21