BUILDING DESIGN AND MATERIAL SELECTION

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ABSTRACT

Studies of indoor air quality (IAQ) and occupant health and comfort only identify associations of risk factors without demonstrating causality. Logical analysis and the dominant evidence point to certain root or primary risk factors. Designers can best target their IAQ control efforts based on analysis of identified risk factors and logical plausibility. A process is proposed to target design efforts to have maximum impact on primary or root building factors that contribute to the prevalence of Sick building syndrome and building related illness. Some key factors are identified and general design considerations are discussed. Design guidance is given for the major primary or root risk factors.

KEYWORDS
Building design, material selection, indoor air quality, sick building syndrome, building related illness, risk factors, indoor environmental health, building ecology.

INTRODUCTION

The most important building design and material selection indoor air quality (IAQ) considerations ;have been discussed extensively (Levin, 1981, 1987, 1989a, 1991, 1992; Seppänen, 1993). This paper proposes a rational process to focus building design decisions (including material selection) on building-related environmental factors most critical to occupant health and comfort problems. The process should 1) determine the most significant health and comfort outcomes (based on frequency and gravity); 2) analyze the plausible causal environmental factors; and 3) identify the building design elements that control those factors. This process will help designers minimize or eliminate most critical risk factors.

Sick building syndrome (SBS) symptoms ranging from odor annoyance or skin irritation to various "flu-like" symptoms appear to be widespread and significant. Building related illness (BRI) ranging from lung disease to cancer, while apparently far less common, are usually far graver. Woods (1987) suggests that BRI rarely occurs without SBS. Addressing either putative SBS or BRI causal factors might reduce the occurrence of both. Many factors contributing to SBS can, if unattended or exacerbated, result in BRI. Therefore, building environmental risk factors for SBS and BRI should not necessarily be considered as separate and distinct.

Identifying the Most Important Factors

Discussion of building design and material selection in the context of IAQ should be based on the best available knowledge. The largest and most important SBS studies have been reviewed extensively by several authorities including Lindvall (1992), Mendell (1993), Norback (1990), Seppänen (1994), Stenberg (1994), and Sundell (1994). Their findings identify risk factors for occupant SBS symptoms. A logical analysis of SBS risk factors and hypotheses of their causal role(s) were performed by Levin (1989b) by reviewing the highest risk factors in the Danish Town Hall Study (Skov *et al.* 1987). Potential synergisms among the factors were postulated Finally, control measures were identified to minimize SBS risks. In this paper, a modified risk factors list is presented from those identified in the meta-analyses that can be addressed by building design and material selection decisions.

SBS risk factors can be categorized as building- or work-related, personal, or psychosocial. Authorities agree that SBS is multifactorial: the environment's impact on occupants can be affected by personal and psychosocial factors as well. Key environmental factors vary within individual buildings, sometimes quite dramatically, as do personal and psychosocial factors. Occupant symptoms vary within buildings and cases of SBS are caused by various combinations of factors. Therefore epidemiologic studies may not detect important associations between building/environmental factors and occupant health and comfort problems. Different study designs also affect the results and can produce inconsistent findings. Some findings, however, do appear frequently and are more logically consistent than others.

This paper focuses on the most frequent and logically consistent building environment determinants of occupant responses as targets for building design and material selection decisions. Selected risk factors found frequently in the major studies, investigations and meta-analyses are shown in Table 1.

Table 1. SBS risk factors identified in major studies and reviews. Initials of lead authors of articles listed in the Reference section.

BUILDING FACTORS		
Low ventilation rates (< 10 L/s p)	(L, M, Se, Su)	
Ventilation operations (<10 h/d)	(Su)	
Insufficient materials control		(L, N)
Fleecy materials	(N, Sk)	
Carpets	(M, N)	
Air-conditioning	(M)	
BUILDING ENVIRONMENTAL FACTORS		
High temperature		(M, Sk)
High humidity		(L)
Low relative humidity	(M)	
Volatile hydrocarbons	(N)	
Microbial VOC	(L)	
Dust		(N)
BUILDING USE / OCCUPANCY FACTORS		
High occupant density	(M)	
VDT use		(M, St, Su)
Photocopiers present		(St, Su)
OCCUPANT FACTORS		
Perception of "dry air"	(St, Su)	

Prioritizing design concern for IAQ

SBS risk factors can be classified in building, environment, and occupant categories. Buildings are complex assemblies of dynamically interdependent systems. A building ecology view states that the building affects and is affected by the occupants and environment - both the indoor and the larger environment (Levin, 1981, 1989b). Building designers can directly impact only the building factors, although it is important that they recognize the secondary impacts of the building on environment and occupant factors. Addressing those building factors that are primary or root factors from among the risk factors in Table 1 presumably will have the greatest impact on SBS symptom prevalence rates.

In addition to the risk factors listed in Table 1, certain factors *a priori* pose important risks. These are potential presence of carcinogens or other genotoxic substances, strong or noxious odorants, irritants, infectious agents, or allergens; extreme temperature or humidity; and, sources of micro-organisms and their amplification and dissemination. A design philosophy of "prudent avoidance" dictates that designers implement practical measures that can reduce or eliminate these *a prior* risk factors. Designer and client judgment as well as regulatory authorities will determine the extent of such control efforts.

"Root factors" are primary or basic; their outcomes are secondary or indirect factors. Elevated temperature is a primary factor because it increases the rate of microbial growth and of VOC emissions from materials. It also affects occupant perception of air quality. Low relative humidity is a secondary factor that may result from or co-vary with elevated temperature and air conditioning. VOCs (including formaldehyde) concentrations result from one or more factors including poor material selection, inadequate ventilation (low ventilation rate or insufficient operation) and elevated temperature. But elevated temperature may also be the outcome of other risk factors such as inadequate ventilation if outside air temperatures are lower than indoor air temperatures.

Table 2. Primary and Secondary Risk Factors for SBS and Their Potential role in SBS or BRI Etiology

Primary Risk Factors	*Secondary Risk Factors*	*Exposure or Role in SBS/BRI Etiology*
LOW VENTILATION Air exchange rate Operational hours Air distribution	Reduced dilution of contaminants	Increased exposures to chemical, physical, and biological contaminant
STRONG SOURCES Building materials Furnishings Occupant activities Consumer/office products Housekeeping materials Maintenance materials Outside air or soil gas	VOC emissions	Increased exposures to odorants, irritants, toxins
TEMPERATURE (elevated)	Microorganism amplification Occupant discomfort Perceived stuffy or stale air	Increased exposure to fungii, bacteria, viruses Increased exposure to airborne VOC
MOISTURE INTRUSION OR ACCUMULATION Leaky building exterior Condensation on surfaces Standing water	Material moistening - high water activity on surfaces High indoor relative humidity	Microorganism growth, Increased occupant exposure to spores, MVOC Odor from MVOC Material deterioration and VOC, particle emissions Increased VOC emissions and exposures

Because the etiology of many (if not most) indoor air related health and comfort problems is "multi-factorial;" it is necessary to understand the linkages among contributing factors. Designers must assess these associations, analyze their design implications, and determine their importance for building design and materials selection. Analysis of the linkages among contributing factors can direct designs to address primary factors rather than their secondary outcomes. Outside air ventilation rate, temperature, moisture intrusion, and strong sources of contaminants are root factors. Elevated airborne concentrations of contaminants result from some one or more of the above root factors. To illustrate, the intrusion of moisture into exterior building walls does not itself cause health or comfort problems. But moisture intrusion results in mold growth and, most likely elevated air levels of volatile organic compounds (VOC) including microbial VOC (MVOC). Designs could specify mold resistant materials (e.g., mineral-based products such as stone or brick) or use fungicide-treated materials, but the root problem is the moisture penetration. High water activity at material surfaces supports fungal growth and competes with VOCs for adsoprtion sites. Preventing or controlling the moisture intrusion will control fungal growth, reduce airborne concentrations of VOCs, reduce indoor air relative humidity, and prolong the life of the building materials and contents. Many comfort and health problems as well as costly remediation measures can be avoided by directly controlling moisture intrusion.

Some factors will have both direct and indirect effects on the building environment and the occupants. Many of these key factors appear more often in research on associations between occupant symptoms and environmental factors..A key primary factor is high indoor air temperature. Occupants are less comfortable at temperatures near the upper end of the thermal comfort envelope, and they are more likely to perceive the indoor air as stuffy or stale (Berglund and Cain, 1989; ASHRAE, 1993). Furthermore, increasing temperature will increase VOC emissions from building materials, furnishings, and other surfaces due to increased vapor pressures. This will increase occupant exposures to VOCs, and microbial growth and occupant exposure to bioaerosols and microbial VOCs will also increase.

Ultimately, the designer and building owner or tenant determine which preventive or mitigative measures to employ in a newly designed or renovated building; Their decisions are based not only on the perceived importance of the measure to reduce the risks of health and comfort problem but also on the feasibility, practicality, and cost of implementing the measures. In most cases, trade-offs are made to achieve the desired outcome. For example, to reduce the concentration of a contaminant emitted from a particular material the decision may be to select low emitting products, to condition or treat the product before installation in the building, or to ventilate the building after installation prior to occupancy. An example is control of 4-phenylcyclohexene (4-PC) concentrations, the characteristic odorous emission from SBR latex backed carpets. The odor threshold for 4-PC is around one ppb while concentrations from newly installed SBR latex carpets can reach 10 to 30 ppb. Typically, after a few weeks of exposure to the environment with reasonable ventilation, the concentration decreases to a level near or below the odor threshold. Building designers may recommend carpets with non-SBR latex backings, they may choose SBR-latex carpets with low 4-PC emissions based on testing, they may recommend airing out the carpet before installation in the building, or they may recommend an extended period of building ventilation after carpet installation before occupancy of the building. Finally, they may recommend increasing the ventilation rate during the initial occupancy period and until some "acceptable" concentration of 4-PC is obtained.

WHAT'S IMPORTANT IN DESIGN

Based on the analysis detailed above, the following design guidance is offered:

SOURCE CONTROL: reduce the indoor air pollutant sources and their source strengths or toxicities by one of the following measures: elimination, reduction, substitution, or source isolation. Important considerations for Material Seclection and Indoor Environmental Quality include Functional Requirements, Surface Characteristics, Total Mass, Chemical Composition and Emissions, Durability - Longevity, and Cleaning, Maintenance and Renovation Requirements.

Ensure adequate VENTILATION to control pollutants that reach the indoor air by reducing and removing them through Dilution, Exhaust (local, general), Filtration, and Air cleaning.

Design for effective MOISTURE PROTECTION to prevent intrusion of water from outdoor through cracks, openings, or semi-permeable membranes and eliminate potential for standing water or condensate inside the building from chilled water systems.

SELECT LOW-EMITTING MATERIALS, especially for those products that will be present in large quantities by mass or exposed surface area.

Design for the WHOLE PERSON: The human body and mind integrate all the factors in the physical, chemical, biological, and psychosocial environment. Full Integration of Environmental Considerations in design will include not only Indoor Air Quality but also Thermal Comfort, Lighting, Acoustics, and Spatial Relationships.

Building Design and Indoor Environmental Quality issues must be considerred throughout the process of planning, designing, construction, using, and recycling buildings. The major design phases include Site Selection, Project Feasibility, Budgeting, Building Configuration, Building Envelope, Environmental Control Scheme, Energy Considerations, and Environmental Impacts Analysis.

DISCUSSION

This paper has emphasized a "building ecology" view of buildings as dynamic, interdependent systems (Levin, 1981). This view argues for planning during the design phase for varying cycles of building performance and use or requirements during the building's lifetime. The more specific the analysis, the more relevant its application to any given building design. Generic analyses are helpful but suffer from the potential to miss important characteristics of a particular situation.

Present space limitations notwithstanding, we could also examine potential co-variance, additivity, potentiation, synergy, and other interactions. The result would be a set of plausible causation hypotheses supported by epidemiologic evidence. We could also describe credible mechanisms to explain the action(s) of the environmental variables on the building occupants. The exercise above reflects an emphasis on the logical plausibility of frequently identified SBS risk factors. It does not fully elaborate the proposed process. Furthermore, a detailed elaboration must be taken in conjunction with a specific building design or at least a reasonable constrained set of building, environmental, and user parameters. Such a detailed examination is beyond the scope of this pape rbut would provide a more reliable set of design priorities.

Finally, we must be aware of the impacts of the building on the larger environment. These will include impacts on the soil, air, and water, on resource depletion, on waste generation, on energy consumption, on biodiversity, global warming, ozone depletion. Some of these will ultimately, although perhaps imperceptibly, affect the building itself and its users. Ultimately, each building must be planned and designed as though it were being replicated a million times over so that we take seriously the consequences of its impacts on the global environment and, in the end, its own environment.

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