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THE EFFECTS OF BUILDING DESIGN AND USE ON AIR QUALITY

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Beginning in the 1970s, with increased emphasis on energy conservation, fan energy savings, and tighter buildings, concerns of occupants about indoor air quality have increased. Various steps taken in the name of energy conservation—the reduced number of air changes, the elimination of operable windows, and the limitation of the practice of "flushing out" a building containing new materials before people move in—have been associated with higher contaminant levels and greater occupant sensitivities. Since people spend 80–90% of their time inside buildings, indoor air contamination at any significant level is bound to lead to increased levels of complaint and possibly to health problems, demanding greater attention to detail from those who design, construct, occupy, and operate buildings.

The concerns about energy conservation that arose in the 1970s led to changes in building design and management without adequate consideration of the corresponding effects on other aspects of building performance. Air quality concerns of the 1980s and the 1990s, if viewed equally myopically, will lead to new design and retrofit measures that may result in a series of failures in other performance areas, paralleling the problems of the energy conservation approaches of the 1970s. These consequences could range from excessive energy use, to increased draftiness, to increased compartmentalization of spaces, or to further removal of individuals from control over their environment (Table 1).[11] Air quality should not be seen as a

*TABLE 1**

A. Sample Performance Failures in Other Areas Resulting from Air Quality Decisions

Decisions made for:	Leading to failures in:
Air Quality	Thermal Performance
Increased ventilation rate	Potential drafts, excessive energy costs
Reduced humidity to slow outgassing and bacterial growth	Inadequate humidity levels
Air Quality	Acoustical Performance
Intermittent air supply	Intermittent sound perceived as noise
Elimination of many synthetic materials	Reduction of available sound-absorbing materials
Air Quality	Spatial Performance
Isolation of polluting machinery—printers, copiers, ovens	Reduced flexibility, less convenient adjacencies
Isolation of polluters, smokers	Reduced communication, proximity, increased social pressures
Isolation of polluting chemicals, cleaning fluids	Less convenient to equipment
Reduced vertical paths/connections between floors (stairs, light wells)	Reduced communication, sense of openness, flexibility
Reduced screening in open plan offices to ensure air distribution	Loss of visual privacy, workspace definition
Air Quality	Visual Performance
Decreased usage of fluorescent fixtures to avoid poor spectral distribution	Decreased lighting efficiency
Air Quality	Building Integrity
Increased humidity for health	Increased condensation potential, corrosion, fungus

(Table 1 continued on p. 645)

disciplinary single-performance issue that can be evaluated or accommodated independently of other performance variables. The "sick building syndrome" is as much representative of thermal, visual, and acoustic quality problems as it is of air quality, requiring a **total building performance** approach to analysis and action.

TOTAL BUILDING PERFORMANCE

The authors believe that a minimum of six performance criteria can capture the performance qualities that must be balanced in buildings: (1) spatial quality, (2) thermal quality, (3) air quality, (4) visual quality, (5) acoustic quality, and (6) building integrity against degradation.[10]

There has been a fundamental mandate over the centuries for building integrity, that is, protection of the building's appearance and critical properties (structural/mechanical, physical/chemical, and visible properties) from degradation by means of moisture, temperature change, air movement, radiation, chemical and biological attack, and natural disasters. Established by concerns for health, safety, welfare, and resource management (energy, time, money), as well as image, the requirements for building integrity are bound by limits of "acceptable degradation," ranging from slight decay, to weakened ability to provide weather tightness or environmental conditioning for function, to total devastation. Secondly, there is a series of mandates relating to interior "occupancy" requirements (not only human occupancy but also artifacts, machines, and plants) and

TABLE 1 (Cont.)

B. Sample Air Quality Problems Resulting from Other Performance Decisions

Decisions made for:	Leading to failures in:
Thermal Performance	Air Quality
Reduced infiltration	Fresh air must be mechanically supplied
Maximum/minimum settings in air distribution systems determined by thermal needs	Inadequate fresh air in smoking areas or copy rooms
Sealed, smaller windows to reduce heat loss	Inability to get fresh air, ventilation by individual
Materials selected for insulation	Potential outgassing
Minimization of outside air intake	Fewer fresh air exchanges per hour
Humidification systems	Potential bacterial growth
Building Integrity	Air Quality
Treatment of wood for preservation (against termites, fungus)	Possible outgassing and toxic effects
Regular cleaning/maintenance of interior finishes	Possible outgassing and toxic effects
Introduction of more synthetic materials over natural materials for ease of maintenance and durability	Possible outgassing, sweating
Elimination of venting of air polluting machines through outside walls for image and weathertightness	Pollution buildup in interior spaces
Acoustical Performance	Air Quality
Isolation of noise-generating equipment	Concentration of potentially polluting equipment
Increased use of sound-absorbing materials	Possible outgassing of binders, release of particulates
Visual Performance	Air Quality
Artificial lighting alone for control and efficiency	Without sunlight, potential psychological dissatisfaction; dying plants; germ and mold build-up
Use of fluorescent light fixtures	Poor spectral distribution; possible radiant and particulate pollution
Spatial Performance	Air Quality
Including garages, food services, printing facilities loading docks within building envelope for convenience	Potential pollution migration
Open vertical and horizontal connections between spaces	Potential pollution migration
Integration of pollution emitting equipment (copiers, for example) within occupied spaces	Pollution buildup
Using mechanical rooms as convenient storage for chemicals, cleaning fluids	Potential pollution buildup and migration
Unrestricted smoking	Particulate pollution

* From Hartkopf et al: Integration for performance. In Rush R (ed): The Building Systems Integration Handbook. New York, John Wiley/AIA, 1985, with permission.[11]

the elemental need for protection (of the five senses for humans), which are dependent on thermal, air, acoustic, visual, and spatial quality. An expanded outline definition of each of these performance mandates is given in Table 2, although only air quality in buildings will be discussed in depth here. Interested readers are referred to references 10 and 11 for further discussion of other performance mandates.

TABLE 2. Six Building Performance Mandates*

- I. SPATIAL PERFORMANCE
  - A. Individual Space Layout: size, furniture (surface, storage, seating); ergonomics
  - B. Aggregate Space Layout: adjacencies; compartmentalization; usable space; circulation/accessibility/wayfinding/signage; indoor-outdoor relationships
  - C. Conveniences and Services: sanitary; electrical; security; telecommunications; circulation/transportation
  - D. Amenities
  - E. Occupancy Factors and Controls
- II. THERMAL PERFORMANCE
  - A. Air Temperature
  - B. Radiant Temperature
  - C. Humidity
  - D. Air Speed
  - E. Occupancy Factors and Controls
- III. INDOOR AIR QUALITY
  - A. "Fresh" Air
  - B. Fresh Air Movement and Distribution
  - C. Mass Pollutants[18]
  - D. Energy Pollutants[18]
  - E. Occupancy Factors and Controls
- IV. ACOUSTICAL PERFORMANCE
  - A. Sound Source
  - B. Sound Path
  - C. Sound Receiver
  - D. Occupancy factors and controls
- V. VISUAL PERFORMANCE
  - A. Ambient and Task Levels: artificial light and daylight
  - B. Contract and Brightness Ratios (glare)
  - C. Color Renditions
  - D. View/Visual Information
  - E. Occupancy Factors and Controls
- VI. BUILDING INTEGRITY (versus visual, mechanical and physical[6] degradation of the structure, envelope, servicing, and interior systems)
  - A. Loads: dead loads, live loads, impact, abuse, vandalism, vibration, creep
  - B. Moisture: rain, snow, ice, and vapor resulting in erosion, penetration, migration, condensation
  - C. Temperature: thermal gradient (insulation effectiveness), thermal bridging, freeze-thaw cycle, differential thermal expansion and contraction
  - D. Air Movement: erosion, abrasion, tearing, air infiltration, exfiltration; pressure differential
  - E. Radiation and Light: environmental radiation, electromagnetic long wave (solar radiation), visible light spectrum
  - F. Chemical Attack
  - G. Biological Attack
  - H. Fire
  - I. Natural Disaster: earthquake, flood, hurricane, tidal waves, volcanic eruptions, etc.
  - J. Man-made Disaster

* From Hartkopf et al: Integration for performance. In Rush R (ed): The Building Systems Integration Handbook. New York, John Wiley/AIA, 1985, with permission.[11]

Total building performance, therefore, is the simultaneous provision of spatial, thermal, air, acoustic, and visual quality within the integrated setting of the occupied building, and the provision of building integrity for the integrated system or building over time.

TABLE 3. Factors Affecting Indoor Air Quality

1. Fresh air availability
2. Fresh air movement and distribution (dilution)
3. Mass pollutants
4. Energy pollutants
5. Occupancy factors
6. Filtration and controls

An Occupant-oriented Definition of Indoor Air Quality

Building-design, construction, and management for acceptable air quality require adequate fresh air intake and fresh air distribution as well as protection from both mass and energy pollutants (Table 3).

The provision of "fresh" air to the building from the outside is the first major problem. It involves the quality of the outside air, the proximity of possible pollution sources, and the avoidance of short-circuiting with building exhausts. These will determine the location and configuration of the air intakes.

Once external fresh air has been introduced into the building, there remains the second task of its distribution, thereby providing ventilation effectiveness. This task must be met not only by the effectiveness of the air-handling within the mechanical system, but also by the effectiveness of the mechanical system within its integrated setting. The relationship of supply registers to return registers, of registers to the enclosed volume to be ventilated, of registers to the position of interior furnishings and structural systems, and the method of control at the local level, will each influence the effectiveness of the interior distribution of the fresh air.

The selection and integration of building materials and processes is the third and equally significant determinant of indoor air quality. Designers must be sensitive in stipulating structural materials, insulations, adhesives, paints, finishes, wallpapers, and even fuels, searching for products with little or no toxic or odoriferous pollutants. Managers and users must be careful to avoid introducing pollutant concentrations in the form of materials, processes, and occupancy behaviors.

Protection from mass pollution[18] includes concern for airborne substances, gases, and vapors, as well as viable and nonviable particulate matter. Viable particulates are biological organisms such as viruses, bacteria, fungi, and spores, whereas nonviable particulates include mists, aerosols, fogs, fumes, dusts, and smokes.

Protection from energy pollution[18] includes protection from ultraviolet, infrared, and visible radiation. The electromagnetic spectrum, in which these waves lie, also includes ionizing, microwave, and radiofrequency radiation, which also have to be considered in certain circumstances.

Many of these indoor air pollutants can be minimized through various building design and management methods: (1) the elimination of the pollutant source and concentrations; (2) the reduction or dilution of the pollutant source; (3) the isolation or the shielding of the pollutant source; and (4) filtration. Of these methods, the elimination of the indoor air pollutant is the most effective and can be achieved by product/material substitution and/or behavioral modification. Ventilation is the next most effective step when dealing with most mass pollutants, whereas isolation is critical for energy pollutants (Table 4).

TABLE 4. Comparison of Methods for Reducing Indoor Air Pollution

Method	Advantages	Possible Disadvantages
1. Flush pollutant from building	Need not alter sources Often only moderately expensive	Lose energy Affected individuals still exposed to low levels Polluted outside air contaminates intake
2. Exteriorize pollutant	Need not alter sources Reduces air infiltration and energy loss Reduces air exfiltration and condensation	Barriers not perfect Seal may deteriorate
3. Scrub indoor air	Need not alter sources Reduces ventilation needs and saves energy	Expensive Affected individuals still exposed to low levels
4. Substitute materials/systems	Affected individuals no longer exposed Reduces ventilation needs and saves energy	Sometimes expensive Substitutes often difficult to obtain
5. Seal in pollutant	Reduces or eliminates exposure to affected persons Reduces ventilation needs and saves energy Often relatively inexpensive	May introduce alternate pollutants Barriers not perfect Seal may deteriorate
6. Treat pollutant	Reduces or eliminates exposure to affected persons Reduces ventilation needs and saves energy	May introduce alternate pollutants Not always possible Not always 100% effective
7. Separate people from pollutant or remove pollutant	Reduces or eliminates exposure to affected persons Can sometimes be inexpensive (e.g., put volatiles in shed)	Not always possible Can sometimes be expensive (e.g., remove UFFI)
8. Isolate affected people	Reduces or eliminates exposure to affected persons Can be relatively inexpensive	Not always possible Creates social isolation and restricts affected persons

* From Indoor Air Pollution and Housing Technology: Research Report. Toronto, Canada Mortgage and Housing Council, 1983.

Establishing Standards for Physiological, Psychological, and Sociological Limits of Acceptability

Although comparatively few standards have been set for indoor air quality, the standards-setting organizations (American Society for Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], International Standards Organization [ISO], Occupational Safety and Health Administration [OSHA], and ASTM) are working to establish new guidelines and consensus standards based on physiological limits of acceptability to avoid long-term health damage.[4,5] In most cases, however, these physiological limits define only extremes, equating to the early thermal standards for avoiding frostbite or heat stroke, rather than the concept of "comfort" as described in the more developed thermal standards of today. Newer standards, such as ASHRAE 55-81,[1] now recognize comfort as distinct from damaging health effects. For example, thermal comfort (and lack of stress) is determined by at least six variables, including two occupant-based conditions, to ensure that 80% of a building's occupants will be satisfied within this multivariant thermal comfort zone (Fig. 1).[15,16] What is not recognized in even these advanced thermal standards is that the comfort zone for an active executive (1.5 MET) in a three-piece summerweight suit (1.3 clo) with the option to move the desk away from a drafty air supply toward the sunny window area *does not overlap* with the comfort zone of a seated typist (1 MET) in a summer dress (0.6 clo) and immobile beneath the air supply. In addition, these more advanced thermal standards promise comfort only for 80% of the healthy population, inadequately dealing with the sensitivities of the elderly, the infirm, and the young. These advanced standards also do not acknowledge an obligation to the remaining 20% of building occupants, or the possibility that discomfort may be as much a result of sociological conditions (only the boss controls the thermostat) or psychological conditions (cool blue colors, no sunlight) as they are a result of physiological conditions.

Indeed, in undertaking an effort to establish an air quality "comfort zone" (rather than a physiological "non-damage zone"), researchers must not ignore the psychological and sociological components of air quality (Table 5).[11] Setting psychological limits of acceptability for indoor air quality requires significantly different parameters, because they are often associated with the sense of smell. Building occupants often attribute alleged poor air quality to bad smells, even if those smells contain no measurable harmful pollutant. Complaints of stuffiness, which may be the physiological reaction to inadequate fresh air supply, may also be the psychological reaction to comparatively overheated spaces, indicating the interrelated nature of air quality and thermal comfort.[14] On the other hand, healthy plants in clean, naturally ventilated, and daylit spaces can act as a positive reinforcement of the occupants' perception of a healthy surrounding (as well as producing oxygen, increasing relative humidity, and acting as organic filters). It is significant to note at this point that German office standards today recommend that no individual should have to work without daylight and a view to the outside—a voluntary guideline[2] dictating floor and window sizes that is having widespread influence on new construction.

Sociological limits of acceptability for indoor air quality focus on the issue of individuals not making decisions for the group, and on such social taboos as uncontained toilet smells and human sweat. Nonsmokers find it increasingly unacceptable to share the same air with smokers, even if the contamination is well below the legally acceptable limit. Building occupants often resent the dictatorial circumstance of centralized environmental control, given little or no input into fresh air delivery, air temperature, air speed and direction, or even control over the few methods for successfully dealing with these sociological (and associated physiological) concerns.[8] This strategy not only calls for occupancy control over the quantity, direction, and temperature of air supplied (through diffusers and/or windows), but also the ability on the part of the occupant to isolate himself or herself from unacceptable materials, components, equipment, processes, even people (note the growth of nonsmoking floors in hotels).

For all of these reasons, the development of new air quality standards for buildings should: (1) include the multiple variables that contribute to air quality, including several occupant-based conditions (age, health, activity); (2) recognize the sociological and psychological limits of acceptability (such as the need for access to operable windows), in addition to the physiological limits that are more easily measured; and (3) promote local control capability tied to the changing workplace rather than blanket control at a building-wide level.

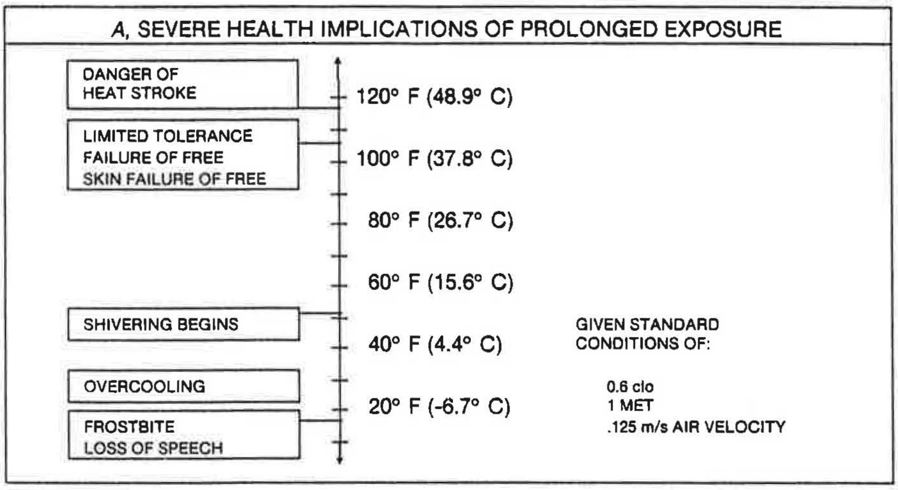
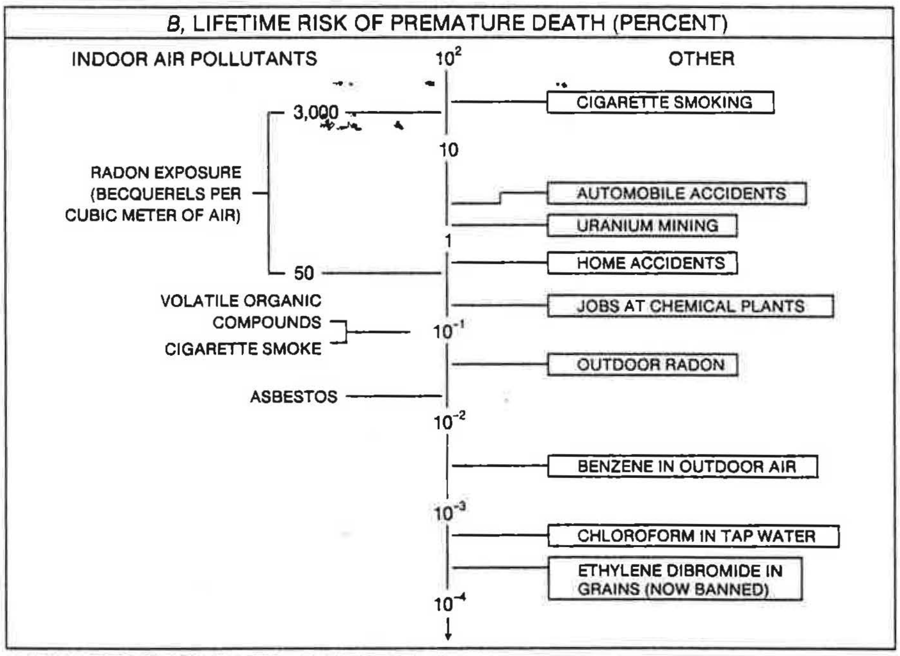


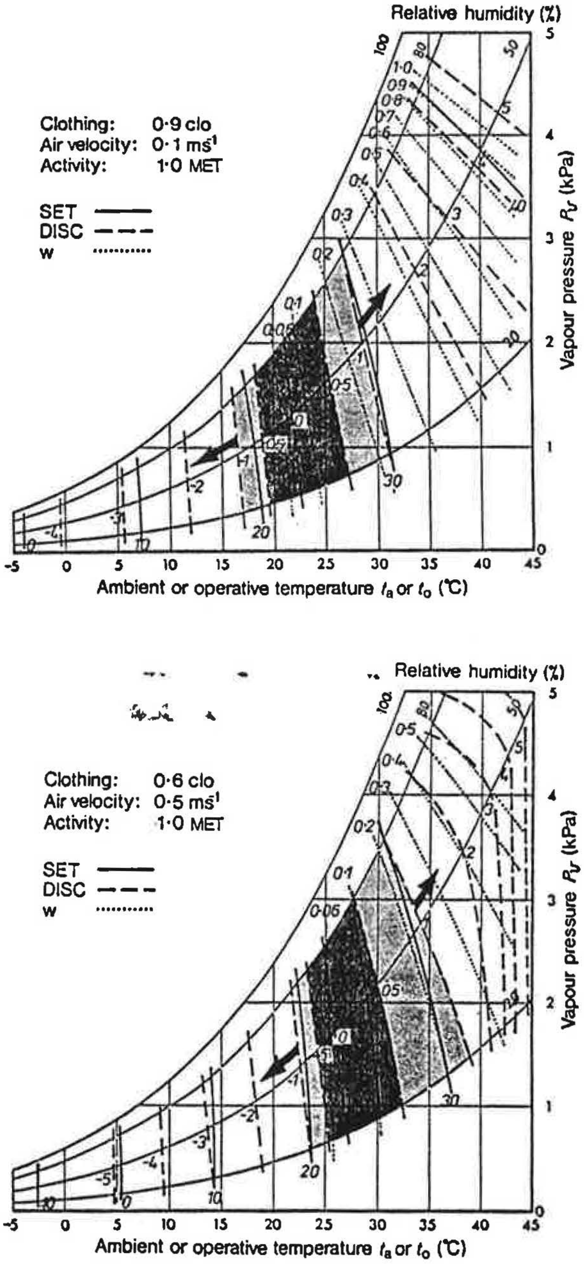
FIGURE 1. (*A* [above and right page]) It took too many years for the experts to move from a simple (single-variable) definition of thermal stress and failure (above) to a multi-variable definition of working comfort (opposite). Even this five-variable definition of acceptable working comfort (forming ASHRAE 90–81 design minimums) does not recognize that the comfort zone for a male businessman in 1.2 or more clo sitting away from the air diffuser *does not overlap* with the comfort zone for a female worker in 0.6 clo sitting (forcibly) under an air diffuser. (*B*, below) Correspondingly, how long will it take for the experts to move from extreme limits for acceptable pollutant levels based on severe sickness or death, to multi-variable definitions of acceptable working comfort levels?



ESTIMATED PROBABILITY of suffering a fatal disease is substantially higher for exposure to indoor air pollutants than for exposure to the pollutants in outdoor air, drinking water and food. The risk of death from exposure to indoor pollutants, however, is no more than that from certain voluntary activities, such as smoking, and occupational hazards, such as those faced in mining uranium.[16] From Nero AV: Controlling indoor air pollution. Scientific American, May 1988, with permission.

FIGURE 1A. (Cont.)

WORKING COMFORT GIVEN 5 MINIMUM VARIABLES*



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* From Markus and Morris: Peoples' response to the thermal environment. In Buildings, Climate and Energy. London, Pitman Publishing, 1980, with permission.

TABLE 5. Organizing Performance Criteria for Evaluating the Integration of Systems*

	Physiological Needs	Psychological Needs	Sociological Needs	Economic Needs
Performance Criteria Specific to Certain Human Senses, in the Integrated System				
1 Spatial	Ergonomic Comfort Handicap Access Functional Servicing	Habitability, Beauty, Calm, Excitement, View	Wayfinding, Functional Adjacencies	Space Conservation, First Cost and Running Cost Effectiveness
2 Thermal	No Numbness, Frostbite; No Drowsiness, Heat Stroke	Healthy Plants, Sense of Warmth, Individual Control	Flexibility to Dress w/the Custom . . .	Energy Conservation, First Cost and Running Cost Effectiveness
3 Air Quality	Air Purity; No Lung Problems, No Rashes, Cancers	Healthy Plants, Not Closed in, Stuffy; No Synthetics	No Irritation from Neighbors, Smoke, Smells	Energy Conservation, First Cost and Running Cost Effectiveness
4 Acoustical	No Hearing Damage, Music Enjoyment, Speech Clarity	Quiet, Soothing; Activity, Excitement, "Alive"	Privacy, Communication	First Cost and Running Cost Effectiveness
5 Visual	No Glare, Good Task Illumination, Wayfinding, No Fatigue	Orientation, Cheerfulness, Calm, Intimate, Spacious, Alive	Status of Window, Daylit Office, "Sense of Territory"	Energy Conservation, First Cost and Running Cost Effectiveness
6 Building Integrity	Fire Safety; Struct. Strength + Stability; Weathertightness, No Outgassing	Durability, Sense of Stability, Image	Status/Appearance Quality of Const. "Craftsmanship"	Material/Labor Conservation, First Cost and Running Cost Effectiveness
Performance Criteria General to All Human Senses, in the Integrated System				
	Physical Comfort Health Safety Functional Appropriateness	Psych. Comfort Mental Health Psych. Safety Esthetics Delight	Privacy Security Community Image/Status	Space Conservation Material Conservation Time Conservation Energy Conservation Money/Investment Conservation

* From Hartkopf et al: Integration for performance. In Rush R (ed): The Building Systems Integration Handbook. New York, John Wiley/AIA, 1985, with permission.

There is a significant amount of research to be done if the standard-setting organizations hope to establish parameters for an air-quality "comfort zone" reflecting psychological and sociological as well as physiological concerns, rather than the "non-damage zone" presently being pursued independently for each identifiable pollutant. Once such standards have been developed, the task of design professionals will be substantially easier to fulfill.

TABLE 6. Critical Component Integrations for Achieving Performance Quality in the Workplace

Component/Assemblies	Funct./ Spatial Quality	Thermal Quality	Air Quality	Acoustic Quality	Visual Quality	Building Integrity
Structural	●	●			○	●
Enclosure		●		○	●	●
Interior	●	○	●	●	●	●
Servicing/Mechanical	○	●	●	○	●	●
Structural Enclosure	●			●	○	
Structural Interior	●			●	○	
Structural-Mechanical Servicing	●	○	○	●	●	
Enclosure-Mechanical Servicing	●	●	○	○	●	●
Enclosure-Interior	●	●	●	●		
Interior-Mechanical Servicing	●	●	●	●	●	●

● Primary Relationship
○ Secondary Relationship

* From Hartkopf et al: Evaluating the quality of the workplace. In Lueder R (ed): The Ergonomic Payoff: Designing the Electronic Office. New York, Nichols Publishing Company, 1986, with permission.

COMPONENTS, SYSTEMS, AND SYSTEM INTEGRATION AFFECTING AIR QUALITY

This section discusses the various building subsystems and their relative contribution to indoor air quality, as well as their interactive contribution. Table 6[12] outlines the primary relationship between major building subsystems and the delivery of various performance qualities, as well as subsystem integrations that are critical to the delivery of each performance quality.

Mechanical Systems May Be the Worst Offenders in Poor Building Air Quality

There are a number of decisions in the design, operation, and maintenance of a building's heating, ventilating, and cooling systems (HVAC) that have been leading causes of building-associated illness. The selection of system type (air, water, or combined) and its control (e.g., variable air volume [VAV], terminal reheat) are critical to air quality performance in a building, as well as longer term system reliability and flexibility. Yet these decisions are not debated and are often determined by whatever is cheapest. A discussion of the air quality failures that occur in buildings owing to HVAC design and management is described in the article on pages 625 to 642. A list of the design decisions that must be carefully and collaboratively made is shown in bold in Table 7.[11] The most notable HVAC failures[3] include: (1) badly maintained air systems, including their filters and humidifiers;

TABLE 7. System Decisions, with Critical Implications for Air Quality*

AIR QUALITY

To Achieve Appropriate:
1. Fresh Air Movement
2. Fresh Air Movement and Distribution
3. Mass pollutants
4. Energy Pollutants
5. Occupancy Factors

*To improve air quality and to foster design innovation, examine any two **bold-faced** systems decisions.*

PHYSICAL DECISIONS IN MECHANICAL SYSTEM DESIGN

- <u>HVAC</u>
Service Generators
  - **Size, Volume**
  - **Form, Configuration**
  - **Expansion Capability**
  - Material, Ornament

Service Conduits
  - **Thickness, Volume of Service**

Form, Shape
  - Configuration, Distance, rise/run
  - **Interface/Expansion Capability**
  - Material, Ornament
  - Connection to Other Systems
  - **Access**

Service Terminals
  - **Planning Module**
  - **Number, Size, Capacity**
  - Form, Material, Ornament
  - **Interface/Expansion Capability**
  - **Relocation Capability**
  - **Connection to Other Systems**

Control Systems
  - **Central Management Systems**
  - **Local Management—Automatic/Manual**

- <u>Lighting</u>
Service Generator—Size, Capacity
Service Conduit
  - Thickness, Volume of Service
  - Interface, Expansion Capability
  - Material, Ornament
  - Access

Service Terminals
  - Planning Module
  - Size, Capacity
  - **Form, Material, Ornament**
  - Interface, Expansion Capability
  - Relocation Capability
  - Connection to Other Systems

Control Systems
  - Central Management
  - Local Management, Automatic/Manual

- <u>Telecommunications, Power, and Security</u>
Service Generator—Size, Capacity
Service Conduit
  - Thickness, Volume of Service
  - Interface/Expansion Capability
  - Material, Ornament
  - Access

Service Terminals
  - Planning Module
  - Number, Size, Capacity
  - Form, Material, Ornament
  - Interface/Expansion Capability
  - Relocation Capability

- <u>Plumbing and Fire Safety</u>
Service Generator—Size, Capacity
Service Conduit
  - Thickness, Volume of Service
  - Configuration, Distance, rise/run
  - Interface/Expansion Capability
  - Access

Service Terminals
  - Planning Module
  - Number, Size, Capacity
  - Form, Material, Ornament
  - Interface/Expansion Capability
  - Relocation Capability

- <u>Vertical Transport</u>
Size, Volume of Service
Form, Configuration
Planning Module
Expansion Capability
Material Ornament

PHYSICAL DECISIONS IN ENVELOPE SYSTEM DESIGN

Exterior Wall/Roof/Floor
  - Exterior Surface, Material Properties
  - Composite Materials, Thickness
  - **Interior Surface**
  - Form: Planar, Curved
  - Slope, Orientation
  - **Module Size, Shape**
  - Connection of Envelope Components

Windows/Openings
  - Material Properties
  - Size, Shape, Spacing
  - Orientation
  - Control Systems, Sunshading
  - Control Systems, Heat Loss

Control Systems, Security/Privacy
  - **Frame, Connections**
    - **Plan/Sec/Elev.**

Access, Visual and Physical
Expansion Potential, Horiz. & Vert.
Change Potential for Access & Image
Color, Texture, Ornament

PHYSICAL DECISIONS IN INTERIOR SYSTEM DESIGN

Ceiling
  - **Ceiling Height, Shape, Form**
  - Ceiling Depth
  - **Ceiling Surface, Material Properties**
  - **Planning Module**
  - **Connection to Other Interior Systems**

Floor
  - **Floor Depth**
  - Floor Form/Slope/Steps
  - **Floor Surface, Material Properties**
  - **Floor Module**
  - **Connection to Other Interior Systems**

Wall
  - Wall Form, Depth
  - **Openings (Interior)**
  - **Wall Surface, Material Properties**
  - Planning Module
  - **Connection to Other Interior Systems**

Furnishings
  - **Work Surface: Material,** Height Depth
  - Sit/Sleep Surface: Material, Ergonomics
  - **Storage**
  - Vegetation/Ornamental Objects
  - Connection to Other Interior Systems

Office Equipment and Appliances
Access/Circulation
Security Configuration
Expansion Potential, Horiz. & Vert.
Change Potential for Access & Image
Color, Texture, Ornament

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* From Hartkopf et al: Integration for performance. In Rush R (ed): The Building Systems Integration Handbook. New York, John Wiley/AIA, 1985, with permission.

(2) poor ventilation controls (e.g., dampers not functioning, VAV shutoff of fresh air if there is no thermal demand); (3) no provision for fresh air intake; (4) no room exhaust; and (5) ceiling supply diffusers too far away or blocked.

In addition, the design of the vertical and horizontal shaft spaces for mechanical systems, power, telecommunications, elevators, and plumbing services will also affect pollution migration. The investment in the mechanical system—the generators, distribution systems, terminal unit density, and their maintainability—are critical to the thermal and air quality of a building over time. Although these systems are not as showy as the front lobby, they are much more difficult to fix—so much so that the *client* should select the best engineer and ensure that the investment in the HVAC be as appropriate as the investment in the interior and exterior finishes.

Interior Components: Serious Culprits in Poor Building Air Quality

The specifications, installation, and maintenance of the materials and surface finishes of a building's walls, floors, ceilings, and furnishings are often the most immediate sources of problems with indoor air quality. Synthetic materials, insulations, plywoods, paints, glues, and cleaning and deodorizing chemicals, to name a few, have all been associated with building-associated illness (see articles on pages 667 to 712). In addition, the lack of appropriate zoning (sealing off of spaces with dedicated ventilation) for polluting activities (garage/loading, printing, cleaning, cooking, chemical storage) has heightened the air quality concerns surrounding the ever-changing interior components in buildings. The solution lies with the careful specification of interior materials and surface finishes with each building modification; the controlled installation of new components (into unoccupied and ventilated spaces); the effective zoning of the interior spaces with the HVAC subdivision and control; and with establishing air quality rules for maintenance.

Building occupants can be serious air quality offenders. The introduction of heavy smoking, room deodorizers, excessive dust (even mildew), local appliances that generate pollution, and uncontrolled cleaning and chemical storage, all pose additional air quality concerns in buildings. However, many occupant-caused air quality problems may be beyond individual control (thus the responsibility of building management), including excessive density or activity (METs) for the HVAC system, or heightened sensitivities to mass and energy pollutants among occupants.

Facility managers, facility planners, architects and personnel managers should be equally well-trained in the air quality implications of interior component specifications (see boldface items in Table 7), as well as the critical decision-making needed to integrate interior systems with other building systems for acceptable indoor air quality.

Exterior/Envelope Systems Also Affect Air Quality

The building envelope contributes to indoor air quality through material selection, module or panel size and connections, and through opening location and controls. Some building construction materials and their interior finishes result in outgassing, including insulation, plywood, particle boards, adhesives, and paints. The decision about panel size and connection will over the long term impact the leakiness of the exterior envelope, allowing for thermal migration, moisture migration, and pollution migration. These migrations may occur from

TABLE 8. The "Healthiest" and "Unhealthiest" Buildings Compared (Using the BSS as the Criterion of Health)*

Building Code No.	Sickness score	Organization	Ventilation	Humidity controls	Openable windows	Tinted glazing	Age	% in 1–2 person offices	% Clerical staff
1. All buildings: the healthiest									
081	1.25	Private	Mechanical	—	Yes	No	1980's (refurb.)	95	22
141	1.52	Private	Mechanical	—	Yes	No	1980's	90	43
021	1.53	Public	Natural	—	Yes	No	1950's	80	73
053	1.54	Private	Natural	—	Yes	No	1960's	20	38
151	1.63	Private	Natural	—	Yes	No	1920's	65	23
2. Air conditioned buildings: the healthiest									
211	2.12	Private	VAV	Steam	Yes	No	1980's	50	27
051	2.25	Private	VAV	—	Yes	No	1980's	30	14
251	2.60	Private	VAV	Evaporative	No	No	1980's	90	60
3. All buildings: the least healthy									
161	4.26	Public	Induction	Spray	No	Yes	1970's	12	23
102	4.29/72	Public/ Private	Induction	—	No	Yes	1970's	20/30	60/64
041	4.76	Public	VAV	Spray	No	Yes	1970's	9	45
293	4.91	Public	Induction	Spray	No	Yes	1970's	1	93
291	5.08	Public	CAV	Steam	No	Yes	1970's	1	86

* From Wilson and Hedge: The Office Environment Survey: A Study of Building Sickness. London, Building Use Studies, Ltd., 1987, with permission.

the inside out (such as room humidity condensing, and rotting and molding in walls) or from the outside in (such as loading dock pollution migrating in through building cracks). Most significantly, the design of the building's openings is key to effective air quality performance, from the location of building air intakes and exhausts, to the selection and design of operable windows (see positive association with healthy buildings in Table 8).[17] Mechanical engineers will often argue that operable windows are not viable options in pressurized commercial buildings, whether large or small. It is our contention that the natural/mechanical ventilation interfaces can be effectively resolved, and that a significant percentage of problem buildings (especially those related to short-term outgassing) could have been prevented through the provision of well-designed operable windows within the occupants control.

Even the Structural System Design Affects Indoor Air Quality

Although a building's structure is usually not implicated in issues of indoor air quality, there are a number of structural design decisions that are critical: (1) the design of vertical and horizontal shafts, as well as their encapsulation against pollution and thermal and fire migration; (2) the structural allowances for effective HVAC sizing, and the configuration for uninterrupted vertical movement in the core and horizontal movement in the ceiling or floor; (3) the tightness of the connections that are possible with exterior and interior wall, floor, and ceiling systems (also critical to avoid pollution migration); and (4) the possible emission of mass or energy pollutants from the structural material itself (such as radon), or from the protecting or finishing material (such as asbestos or loose mineral fiber fire protection). For example, system repairs and modifications

TABLE 9. Examples of Integrated Decision-Making Critical to Performance*

	Integrate Envelope and Interior Systems for:
Air Quality	• air tightness of envelope • effective compartmentalization vs. pollution migration • outgassing prevention through material selection • airflow patterns, adequate fresh air • individual control/compartmentalization
	Integrate Structure and Envelope Systems for:
Air Quality	• elimination of vertical pollution migration paths and structure • envelope tightness against air leakage • space allocation for local mechanical air distribution
	Integrate Structure and Interior Systems for:
Air Quality	• connection tightness to stop pollution migration • protection against potentially polluting building materials • adequate ceiling plenum space for air distribution
	Integrate Mechanical and Interior Systems for:
Air Quality	• fresh air distribution effectivenss • flushing vs. outgassing • protection from radiant pollution • individual control, compartmentalization vs. pollution migration
	Integrate Envelope and Mechanical Systems for:
Air Quality	• adequate fresh air intake; no short circuiting with exhaust • mechanically introduced air versus air infiltration • coordinated management for natural ventilation
	Integrate Structure and Mechanical Systems for:
Air Quality	• volume, form for effective air distribution and flexibility • no blockage of mechanical distribution by structural elements • air tightness of S & M verticals versus pollution migration

* From Hartkopf et al: Integration for performance. In Rush R (ed): The Building Systems Integration Handbook. New York, John Wiley/AIA, 1985, with permission.

often have to be accomplished in ceiling plenums. The structural steel fire coating can become disturbed under those circumstances and can migrate through the HVAC system or "land" in the occupied space.

System Integration Is Equally Important for Long-term Air Quality

One might presume that if building-design decision-makers (the architect; the mechanical, electrical and structural engineers; the interior designer; and the facilities manager) each did his/her independent job effectively, that one would have excellent air quality. However, many air quality failures result from the poor integration of otherwise perfectly acceptable components and systems.

Table 9[11] illustrates a number of the integration decisions that are critical to air quality; a few are worthy of comment here. The lack of coordination between envelope and interior wall or ceiling systems often results in incomplete compartmentalization of interior rooms, allowing for pollution migration. Similarly, poorly integrated structural and enclosure systems result in poor connections, allowing outdoor pollution to enter in; and poorly integrated structural (e.g., round columns) and interior wall systems result in poor connections, allowing localized pollution to migrate. The worst culprit in many instances is the poor integration of mechanical systems with the eventual interior systems. A vast number of buildings[3] have demonstrated inadequate diffuser capacity for occupancy density and compartmentalization, inadequate diffuser location in relation to occupancy layouts (and subsequent re-layouts), and inadequate density of controls for the range of activities and climatic loadings, as well as controls located in the wrong interior zone. Finally, the ineffective integration of envelope systems and mechanical systems has often resulted in inappropriate fresh-air intake locations, and the short-circuiting of the building exhaust with intakes. More seriously, the ineffective integration of the envelope and mechanical systems (caused by the lack of integrated decision making between design and engineering disciplines) has contributed to the widespread avoidance of operable windows even in medium rise buildings—a significant factor in the increased occurrence of building-associated illness.

What is the implication of this lack of integrated decision making? For more than 40 years since the advent of central air conditioning, the architectural profession has abdicated the provision of thermal quality in buildings (and by association air quality) to mechanical engineers, furthering the subdivision of responsibility by system type. This division of responsibility is inadequate since it leaves one primary decision maker for each major set of components, suggesting a minimum of conflict in the building delivery, with clear role definitions (Table 10A). However, the ultimate provision of such performance criteria as air quality and spatial, thermal, acoustic and visual quality, as well as long-term building integrity, depends largely on the effective integration of building systems within the occupied setting. Indeed this division of responsibility by components/system establishes that only one decision maker, the mechanical engineer, is by default responsible and accountable for air quality at a building's completion, yet as a subconsultant has no control over all of the other components/systems that equally affect building air quality. Then, at occupancy, the building manager/operator becomes responsible and accountable for indoor air quality and yet also has little control (and in many cases no input) over the actual decisions that affect air quality, such as the selection of mechanical systems; the selection of building materials; space layout and density; and the addition of new office equipment and processes. Only preventive maintenance of the preselected mechanical systems and system retrofits is within the building operator's control.

To widen these gaps in decision making (and accountability) further, the field evaluation of buildings is also divided into component/system disciplines. Field evaluation techniques are often tied to component groups—evaluating enclosures for degradation, mechanical systems for thermal or air quality, and interior systems for spatial or acoustic quality. Although the subdivision of expertise may be logical given the body of knowledge needed, the disciplinary recommendations that result can be totally unacceptable. For example, an interior designer who is accountable for interior systems but not air quality may recommend the widespread introduction of acoustic screens in an open office that has serious privacy problems because of noise pollution. Although the acoustic problem may have been solved to some extent, the interior system retrofit may cause serious lighting and air quality problems; for example, the 80-inch screens that were introduced throughout the office area could not be effectively coordinated with the ceiling lighting, causing shadows and low light levels; and the high screens sat flush with the floor, causing the fresh-air flow

*TABLE 10.**

A. Old Alliance of Disciplines with Components

	Professional Disciplines							
Delivery of Components	Architect	Interior Designer	Mechanical Engineer	Structural Engineer	Electrical Engineer	Lighting Designer	Energy Consultant	Acoustical Consultant
Structural				●				
Enclosure	●						○	
Interior	○	●						○
Mech-HVAC			●				○	
Mech-Elec					●	○		
Mech-Lighting					○	●		

B. New Alliance of Disciplines with Performance

	Professional Disciplines							
Delivery of Components	Architect	Interior Designer	Mechanical Engineer	Structural Engineer	Electrical Engineer	Lighting Designer	Energy Consultant	Acoustical Consultant
Spatial Quality	●	●	○	●	●	●	○	●
Thermal Quality	●	●	●	○		●	●	
Air Quality	●	●	●			○	●	
Acoustic Quality	●	●	○	○		○		●
Visual Quality	●	●	○	○	●	●	●	
Bldg. Integrity	●	●	●	●	●	●	●	○

● Primary Relationship
○ Secondary Relationship

* From Hartkopf et al: Evaluating the quality of the workplace. In Lueder R (ed): The Ergonomic Payoff: Designing the Electronic Office. New York, Nichols Publishing Company, 1986, with permission.

from the ceiling diffusers to bypass the workplace altogether, short-circuiting into the return air grill.

For this reason, the authors of this chapter strongly recommend that the delivery process of a new building or a retrofit project be managed so that the various design disciplines be held accountable for the ultimate performance of the occupied setting (thermal, visual, acoustic, spatial, and air quality) rather than for a discrete set of building components or systems (Table 10B). A collective decision making process (often called team decision making) must be established at the outset of a project, holding the entire team accountable through the first year of occupancy for overall performance quality instead of component groups. Only this action will entice design "subcontractors" (who have had limited responsibility or accountability in the past) to enter actively into associated decision making areas to ensure long-term building performance.

INDIVIDUAL CONTROL CONCEPTS: AN OPPORTUNITY TO PROMOTE THE INTEGRATION OF MECHANICAL, INTERIOR, AND ENCLOSURE SYSTEMS

It is time for the building community to develop a layered approach to building control, breaking away from the currently predominant central building control systems.[8] This shift requires installing appropriate *levels* of control, possibly as fine-tuned as each individual or each room, but at least at multiple zones, instead of maintaining decision and control at floor-wide or building-wide levels only. Again, many performance failures in buildings may be psychological and sociological. "Big Brother" systems that make all environmental decisions (heat, air, light, sound) for the building occupants are likely to undermine psychological and sociological well-being. In addition, these centralized systems most often do not have adequate subdivision capability to cope with the different environmental needs of the many and frequently changing functional spaces on a floor.

This need for more individualized control could be met by decentralized systems with local controllers, with some load balancing or heat/cooling recovery for energy efficiency. Alternatively, splitting task and ambient systems in each performance area (thermal, air quality, light, sound) would allow for user refinement of the individual space environment, while allowing a "loose fit" setting in the building as a whole, to accommodate major changes over time. This task and ambient control concept is based on creating a centralized, technically controlled, ambient environment and a localized user-controlled task environment. This concept extends far beyond the provision of ambient lighting for circulation and individually controlled task lighting to: (1) ambient and task heating and cooling; (2) ambient and task fresh-air supply; (3) ambient and task sound masking; and even (4) ambient and task spatial definition. In each case, a marginally acceptable ambient environment would be "optimized" by a central building management system with environmental input (and possibly user input) for health, safety, and economy. User acceptable task environments would then be optimized by individual controls with environmental and occupant sensitivity input (and possibly central management commentary) for welfare, satisfaction, and resulting productivity.

One example of a commercially available system of split-task and ambient environmental conditioning systems is the Personal Environments system (Fig. 2).[13] This workstation "harness" for open office work areas allows the occupants to set their own environmental requirements in all performance areas, with task heat (radiant panels and local supply air temperature), task light, task *fresh air* (ducted), and air speed and direction, as well as task sound-masking for the open work areas. Ambient environmental conditions to meet a much more lenient "comfort zone" are provided by a centralized system with input from all of the individual system contributions. Personal Environments marks an important milestone in the development of compatible high-performance individual or task control systems and loose-fit ambient control systems.

The interfacing of individual occupant control for various environmental qualities with the building-wide controls will contribute significantly to more successful overall building performance, including air quality, and enhance individual well-being and productivity.

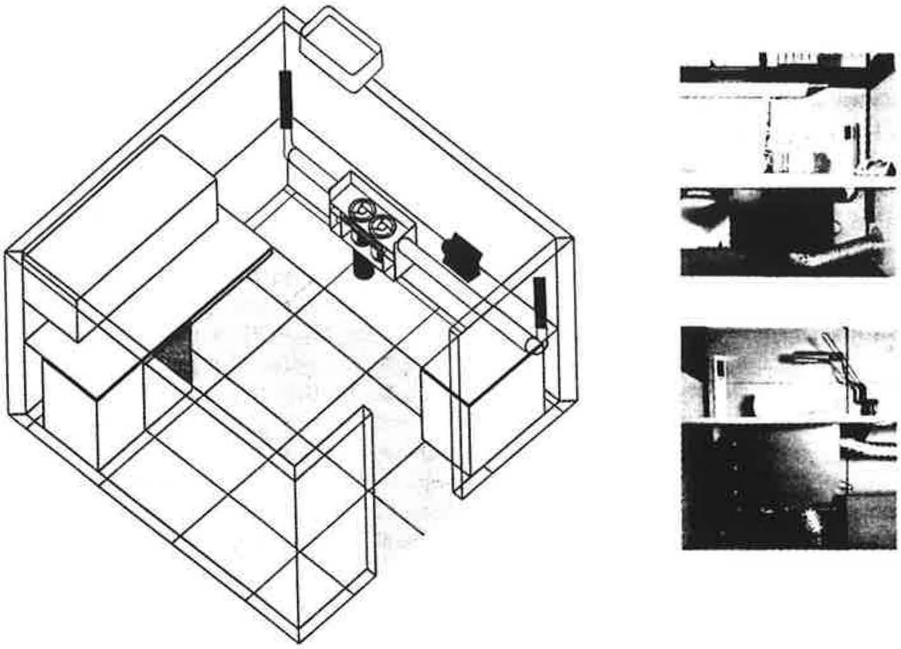

FIGURE 2. The Personal Environments concept from Johnson Controls most importantly brings *ducted fresh air* to each work station in an open-office setting. It also allows for individual control of air speed, air temperature, and air directions, as well as task light, task radiant heat, and white noise. These individual controls for the multiple aspects of environmental quality can go far towards resolving individual activity and sensitivity differences, as well as common building inadequacies.

Don't Shortchange the Occupant

Ensuring total building performance in the design and operation of buildings is dependent on the management process and a consistently positive attitude towards the building occupants. Occupants are a building owner's most important and affordable sensor for overall performance quality in buildings. Although occupants may not correctly identify the cause of nausea, headaches, congestion, and eye problems, they are effective and very reliable sensors. Not only should building complaint records be taken seriously, occupancy questionnaires should be consistently used to anticipate serious (far-reaching or long-range) health hazards in buildings. In addition, since occupants are the most effective local sensor (of thermal, air quality, visual quality, and acoustic quality), major environmental controls should be put back into their hands—in the form of operable dampers, local fans, thermostatic controls, humidifiers, local filters, light switches, and operable windows.

CREATING HEALTHY BUILDINGS (OR AVOIDING AIR QUALITY PROBLEMS IN NEW BUILDINGS AND REMODELING PROJECTS)

Even if we frequently cannot pinpoint the exact causes of building-related illnesses, (or sick building syndrome), we can take steps to avoid conditions that contribute significantly to poor air quality in buildings. In many of these steps, no additional financial investment is required, just careful planning and collaborative, early decision making. Where investment is required, the actions are identified as critical for ensuring a healthy building and for avoiding unacceptable air quality in the first few months of occupancy, or for avoiding years of occupancy dissatisfaction, illness, or litigation.

1. Ensure careful programming of the building

Clearly identify occupant sensitivities for air quality, thermal quality, visual quality, acoustic quality, and spatial quality to establish design requirements and to enforce them through design and construction.

2. Introduce "fresh air architecture" and avoid megaplexes

Buildings of greater than 1000 occupants under one roof should be viewed with concern. In these buildings, occupants lose contact with the outdoors, fresh air, and sunlight, and consequently they lose psychological comfort and in many cases physiological comfort. Introduce "green lungs" into buildings with campus plans, outdoor courtyards, or even heavily treed parking lots; avoid high-rise or low-rise megaplexes. Carefully plan mixed-use facilities (garage and hospital, food service, shopping, and living) to avoid unacceptable environmental influences (noises, exhausts, re-entrainment, excess heat gain or heat loss) and identify zones of similar thermal, air quality, visual, spatial, and acoustic requirements.

3. Insist on team decision making

Hire a project manager for the duration of the project, from early conception through 1 year of operation. Do not presume that the architect of record will have expertise in total building performance, or champion a team decision-making process. Project architects have a vested interest in producing outstanding aesthetics and spatial quality (based on their education), even at the expense of long-term total building performance.

With a project manager, involve the architects, engineers, health/hygiene experts, and a cross-representation of the client groups in a team decision-making process from the beginning conceptual design, including:

a. building size, massing, (e.g., "thin" and highly articulated buildings for increased exposure to outdoors), zoning, and adjacencies;
b. selection of HVAC system (management of source pollution, fresh-air balancing, filtering, humidification);
c. configuration of fresh air intake(s), building exhaust(s), and percent recirculation;
d. integration of HVAC system with massing, organization, enclosure, and interior systems for ensuring "ventilation effectiveness";
e. decisions on central versus distributed (even individual) environmental controls (of heat, cooling, air, light); and
f. selection of interior components and materials.

4. Insist on distributed, even individual, controls or overrides

In each space or room, it is the individual function (with its sensitivities and heat generation) and the individual occupant (with his/her sensitivities) that should determine the level of fresh air (including operable windows), heat, light, and cooling needed. Whole floor or zone controls do not accommodate large variations in function or occupancies. Consider distributed systems, highly differentiated systems with terminal controls or split task/ambient systems.

5. Carefully select interior finishes and furnishings

Using expert consultants, avoid materials with long-term or high-level outgassing, materials that cause skin irritation or sweating, and materials that are hard to maintain and may gather dust or mildew.

6. Introduce expert or peer reviews

Bring in air quality experts and hygienists in the design and working-drawing process. As even a $10,000 book publication gets peer reviews, why shouldn't architectural and engineering drawings for multi-million dollar buildings undergo scrutiny in the design development and working-drawing stages?

7. Field diagnostics

Use field diagnostics to ensure that the performance requirements in the program are being met, testing, for example:

a. in-situ R-values and air leakage of the enclosure walls and windows;
b. the sealing of vertical and horizontal shafts against pollution and fire migration;
c. the noise and efficiency of the HVAC system;
d. the effectiveness of fresh-air provision to the rooms and distribution within rooms; and
e. the presence of unacceptable material outgassing.

8. Establish and pay for a 1-year commissioning process

Keep the architect, the mechanical engineer and the mechanical contractor/installer accountable for 1 year of occupancy to ensure that all of the building systems are installed properly, and balanced to suit the final occupancy conditions. Most mechanical system design problems (not related to maintenance) are easily identifiable in the first year of occupancy.

9. Avoid early occupancy

To avoid early outgassing "sensitization" of the building occupants, ensure that all construction and finishing work is completed well before occupants move in. Insist on adequate flushing of the building (opening windows and operating fans around the clock for several days) to carry away the toxics from adhesives, cleaning fluids, etc.

10. Do not shortchange maintenance and repair budgets

Maintenance and repair budgets for managing HVAC equipment, filters, humidifiers, and adjustments, as well as cleaning programs and chemical storage, are often sabotaged for interior decoration projects and budget cuts. The negative aspects of underfunding maintenance and repair are tremendous, up to and including building obsolescence. Hire and pay for highly trained facilities managers, and pay for their continued training. Involve the facilities manager in all building modification or renovation projects (including computerization) to ensure that the buildings systems can manage the new environmental loads.

11. Oversee renovation projects as conscientiously as a new building project

As with a new building project, evaluate the design for adjacencies, zoning, finishes, furnishings, and new equipment that can cause air quality problems. Absolutely ensure that significant investment is made for the necessary HVAC system modifications to service the interior modifications. Walls are often moved and room functions or occupancies changed without the necessary corresponding mechanical system change.

12. Work with the building occupants

Use information from the building's occupants to uncover and avoid air quality problems. Resolve the rules for smoking, aerosols, cleaning products, printing chemicals, and idling automobiles outdoors. Building occupants are excellent and affordable air quality sensors—lean on routine occupancy questionnaires and complaints records for uncovering potential problems. Develop simple instrumentation capabilities to test for CO_2, fresh air distribution, and particulates.

Table 11 provides a broad checklist of decisions affecting long-term air quality for use in various stages of the building delivery process, and may best serve to summarize this review.

TABLE 11. A Broad Checklist of Decisions Affecting Long-term Air Quality for Use in Various Stages of the Building Delivery Process

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Air Quality Concerns in Planning and Programming

- Appropriate zoning with relation to pollution generators
- Careful programming of mixed-use buildings
- Reconsideration of megaplexes (> 1000 occupants)
- Special User groups
    - aged
    - very young
    - handicapped
    - ill
    - hypersensitive (tight building syndrome)

Who is average?

Air Quality and Preliminary Design

- Building zoning with relation to wind
- Appropriate adjacencies, activities, and air quality needs
- Selection of HVAC system (source pollution, filtering, humidification)
- Integration of HVAC system with massing, organization, enclosure and interior systems
- Configuration of fresh air intake, building air exhaust, percent recirculation
- Commitment to local user controls of air supply, windows, etc.

Air Quality and Design Development

- Avoid pollution migration from "source" spaces:
    - into vertical shafts (elevators, chimneys, exhausts, ducts, cracks)
    - into horizontal plenums
    - due to mechanical short-circuiting
    - due to inappropriate adjacencies
- Design of fresh-air intake, building exhaust, duct lining
- Integration of HVAC with enclosure and interior design
    - number of mechanical zones
    - partitioning with terminal units
    - wall penetrations
- Design of HVAC management
    - central (ECMS)
    - energy efficient vs. effective
    - user/local controls
    - natural ventilation

Air Quality and Design Specifications

- Building material choice and specifications vs. outgassing, radiation, allergic reaction
    - carefully spec stone/concrete (with respect to radon)
    - composition boards (formaldehyde)
    - glues, adhesives (organic pollutants)
    - ceiling tiles, fireproofing (asbestos)
    - roofing asphalt and synthetic fabrics and carpets, foamed plastics, rubber, paints, sealants, caulks, etc.
- Building contents: HVAC and office equipment specification
    - copying equipment
    - gas-, oil-fired equipment
    - humidifiers
    - wood stoves, fireplaces
    - computers and printers

Air Quality and Construction and Acceptance

- Supervision of material usage as specified; local storage
- Supervision of vertical and horizontal shaft seals

Continued

TABLE 11. (Continued)

Air Quality and Construction and Acceptance *(Continued)*
Before move-in:
- Warning—do not push for early occupancy
- Complete all finishing before occupancy
- Allow for adequate flushing/ventilation of building

Air Quality and Maintenance and Operation
- Cleaning schedules and mechanical schedules
- Selection of cleaning chemicals
- Storage of cleaning chemicals
- Maintenance of equipment; filters, humidifiers
- Occupancy awareness about
  - smoking (CO)
  - aerosols (fluorocarbons, vinyl chloride)
  - cleaning products (organic pollutants)
  - automobile exhaust (CO and lead)
- Occupancy controls
  - macro to micro levels
- Sampling: particulates, gases, micro-organism airflow, and percent fresh air

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