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Design Approaches: Low-Pollution, Energy Conserving Building Design, Operation

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ABSTRACT

In recent years, some building design professionals have become more aware of indoor air quality concerns of owners and occupants. As a result, they have made some important changes to improve indoor air quality and climate. These changes include improvements in site planning and design; overall building design; ventilation and climate control systems; and, materials selection and specifications. In addition, changes that limit chemical contamination of building air during the construction process and during occupancy of buildings are also occurring; some of these changes are specified or controlled by design professionals. However, the majority of design professionals have little or no awareness of indoor air quality considerations. There is inadequate communication of building science research results to design professionals. There is a need for a useful general body of knowledge, theory, and practice regarding building-environment-occupant interactions. The absence of such knowledge, theory, and practice is an impediment to developing the necessary professional design tools and practices to address effectively indoor environmental quality and energy conservation issues.

INTRODUCTION

Important building design changes have been occurring during recent years. Many of these changes significantly improve indoor air quality (IAQ) and climate. These changes are being made in response to heightened awareness and concerns of occupants, building owners, and the design professionals themselves. Additionally, building products and materials manufacturers are making and marketing products to improve IAQ (Levin 1989, 1990a, 1990b).

The changes tend to fall in four major categories: site planning and design; overall architectural design; ventilation and climate controls; and, materials selection and specifications. Additonal design and building professional responsibilities related to commissioning of newly-constructed or renovated facilities have developed. Table 1 lists the major phases and subcategories of critical building design control.

[INSERT Table 1 HERE]

MAJOR IAQ CONTROL MEASURES BY DESIGN

Many design approaches to IAQ control have been used in various projects. In this section we identify some of the dominant trends and approaches to provide an overview of the field.

Site Planning and Design

During site planning and design, design professionals address sources of indoor air contaminants in ambient air. These may originate distant from the site or locally. They include gaseous and particulate contaminants generated by motor vehicle, power generation, and industrial process combustion; particulate matter from agriculture, road dust, and wind-generated soil erosion; and, ozone formed by the combination of NO_2 and hydrocarbons in the presence of strong sunlight. Soil gas contaminants including radon and organic chemical compounds can enter buildings through gaps in construction elements in contact with the soil or by direct migration through semi-permeable building materials. Table 2 lists the major elements of IAQ control during site planning and design.

[INSERT Table 2 HERE]

There are several control measures building designers use to control indoor air quality by site planning and design. They evaluate sites prior to acquisition and project planning to avoid problem sites. They locate the building and apurtenances on the site distant from sources or pollutant plumes. They plan vehicular circulation and parking to minimize pollutant concentrations at the building edge, especially air intakes and other openings (Levin 1988, 1989).

Designers and project planners can review and evaluate ambient air quality data and local contaminant sources during feasibility studies. Data are obtained on air quality and climate from local agencies. Soil and water samples are analyzed for potential sources of contaminants. Activities in adjacent and other nearby structures are identified to determine potential pollutant emissions. If necessary, air monitoring is done to evaluate outdoor air quality and proximate pollutant sources. Soils and gaseous soil emissions are tested for volatile organic chemicals (VOC) and radon. Where warranted, mitigation measures including pressure relief systems and more effective sealing of pathways into the building are designed to reduce soil gas or groundwater penetration into the structure (Levin 1988).

Overall Architectural Designs

The overall architectural concept design (or "schematic" building design) includes basic decisions about building shape and size, orientation, layout of floor plans, location of pollutant generating activities, envelope and interior materials, fenestration, and general ventilation concept. Experience shows that many IAQ problems result from decisions made at this stage of the project. Although problems resulting from such decisions can be mitigated by subsequent control measures, it is often more cost effective to begin consideration and design for good IAQ during the schematic design phase. Table 3 lists the major categories of overall architectural design considerations.

[INSERT Table 3 HERE]

Building Openings. Openings through which contaminants might enter are located distant and not downwind from identified pollutant sources outside the building. Interior building areas adjacent to such potential sources of exhaust fumes are positively pressurized to reduce possible entrainment of exhaust.

Operable Windows. In a reversal of the trend toward sealed windows that dominated building designs from the 1960s well into the 1980s, buildings designed recently have often included operable windows. In some instances these are provided as an "emergency ventilation" system in the event of inadequate ventilation by mechanical means. In many such instances occupants are not actually permitted to open the windows; in some cases they are locked in the closed position. When mechanical ventilation is operated to create positive pressure inside a building, opening windows might not provide additional outdoor air.

Some designers provide operable windows to allow occupants the psychological benefits of direct visual access to the outdoor environment as well as to actually allow air directly to enter occupied areas. Installation of a sensor "interlock" for window operation and the ventilation system controls can maintain "balance" in the ventilation system while permitting occupant operation of windows. The sensor sends a signal to the ventilation system controls which then compensate for the change in pressure.

Pollutant Generating Activities. Activities such as food preparation, printing, art, tobacco smoking, certain health care, and others can be sources of contaminants inside buildings. These activities are identified and located away from sensitive areas or occupants. Air flow is controlled to avoid transferring contaminants to adjacent spaces or into a recirculating mechanical ventilation system. Direct exhaust without recirculation is the preferred solution.

Envelope and Structural Materials. Materials are chosen that are known to have low pollutant emissions characteristics. When such materials are not suitable, alternative means of controlling contamination of air in the completed building are used including temporary ventilation, in-place curing, and encapsulation or isolation of materials from the building occupants' air. Where glazing permits direct sunlight to strike interior materials, darkened glass or shading devices are used to minimize such sun entry. This reduces surficial heating of materials and associated episodic elevation of VOC emissions.

Vehicle Access. Motor vehicle access to garages, loading docks, and pedestrian drop-off points are located away from air intakes and building entries. Where openings do occur near vehicle access points, positive building pressure is maintained inside the opening to keep exhaust fumes out.

Basement Dehumidification. Control of microbial contamination in basements is accomplished by reducing humidity. Some designers have developed and tested full-scale installations of sophisticated systems to control humidity as well as soil gas entry into basements in Canadian houses. The Canadian system has also been designed to reduce water leakage and cold floors (Walkinshaw, 1990). Further research and development activities are likely to produce refinements and alternative systems to improve IAQ and climate in basements.

Special Provisions for Polluting Activities During overall building design, identification of occupant activities likely to be sources of indoor air pollutants allows planning for their containment and control. Printing, cooking, art and hobby activities, and other common building occupant functions can be addressed by locating them where their emissions will not adversely affect other parts of the building. By providing separate, dedicated, and properly ventilated spaces, their impacts can be minimized.

Other activities such as photocopying, food preparation, and graphic arts have also been provided increased ventilation, no recirculation, and additional exhaust systems to minimize exposure of building occupants to the contaminants they emit. Special exhausts with inlets close to the pollutant source have been used effectively to control indoor air contaminant levels. (Levin 1988).

Smoking Lounges. Public awareness and new laws have resulted in the design of separate spaces for smoking in some public access buildings. One pass ventilation with no recirculation is usually provided to eliminate exposure of non-smoking occupants to environmental tobacco smoke (ETS).

Ventilation and Climate Control

Ventilation is viewed by many as an essential design strategy for IAQ control. They argue that there are too many sources, the sources are too diverse, and the sources change over time making it impossible to avoid them by design. In particular, contaminants emitted from occupant activities, personal hygiene products, clothing, and other sources are outside the control of the design professional or builder. Therefore, ventilation including dilution of contaminants with cleaner air (either outside air or filtered, recirculated air) is used to control contaminant concentrations to acceptable levels. Table 4 lists the major ventiation design considerations for good IAQ.

[INSERT Table 4 HERE]

Questions exist as to the suitability of outside air for such dilution, about the proper approach for strong contaminant sources, about contamination from the ventilation system itself, and about distribution of ventilation air within the building. Development activity of effective air cleaning to remove gaseous contaminants is currently quite vigorous among filter and air cleaner manufacturers.

Dilution by Outside Air. Dilution and removal of contaminants by ventilation continues to be the principal approach to indoor air quality control. The quantity of outside air used for this purpose is the subject of much investigation and is a driving force in ventilation system design. The issuance of the revised ASHRAE ventilation standard (Standard 62-1989, "Ventilation for Aceeptable Indoor Air Quality") has resulted in some changes, mostly increases, in the quantity of outside air required for ventilation of various occupancy types (ASHRAE 1989a).

Ventilation standards based on outside air supply per occupant have not been shown to be sufficient to control unusual or strong contaminant sources. Adequate ventilation rates must be based not only on the human occupant density but also on the activities that will occur, the types and strengths of contaminant sources, the ventilation system distribution scheme, and the volumetric dimension of the building's spaces.

Air intakes. The known sources of potential contaminants for outside air intakes include exhausts from other buildings, motor vehicles, industrial and agricultural processes, and exhausts from the building itself. Many building designers have begun locating building air intakes distant from various building systems including plumbing stacks, kitchen and toilet exhaust air vents, and the ventilation system itself. In large buildings, cooling towers are located distant from air intakes to avoid entrainment of drift containing water treatment chemicals or microbial contaminants.

Exhaust Locations. Related to air intake design location is building system exhaust location. Designers reduce potential re-entrainment of exhaust air by locating outlets downwind and distant from potential intake sites.

Air Cleaning. Where outdoor air is contaminated, designers specify use of air cleaning and filtration as appropriate. Designers are choosing more efficient media filters or using electronic air cleaners to reduce particulate matter concentrations in ventilation air. Gaseous contaminants have been largely ignored heretofore. However, growing consciousness of outdoor air contaminants and their entry into buildings is leading to the investigation of and specification of adsorbents for improving ventilation air quality.

When indoor air is recirculated with little outside air introduced, air cleaning and filtration is used to remove contaminants from indoor sources. Particles and gases are removed by the means mentioned above. These air cleaning and filtering devices that have been used both in central HVAC components and locally (within or near) the occupied space.

Space Air Distribution. Considerable differences in opinion exist among researchers and engineers regarding the extent to which ventilation supply air mixes within building spaces. Designers in some areas have begun introducing supply air through the floor, at desk top, and from sidewall difusers to improve space air distribution. Return air registers are being carefully placed to avoid short circuiting of supply air to the exhaust system. Supply and return air systems are being carefully balanced to improve space air distribution.

Partial-height partitions in open space offices can block air flow, especially under low flow volume and velocity conditions. Some designers raise partition bottoms above floors to improve air flow and ventilation space air distribution. Others have used supplemental fans to improve space air distribution. Desktop supply inlets and inlets mounted in raised floors have also been used to improve space air distribution as well as energy efficiency of ventilation systems.

Induction units, fan coil units, and local (personal) fans have been used. "Personal" or individual control of such supplemental units has provided occupants with more access to air flow and comfort.

Heat Recovery. In order to maintain indoor air quality without unnecessary loss of energy efficiency, heat recovery systems are now being used. Whe designed to remain in service during maintenance, a high level of performance can be achieved (Greim *et al* 1990).

Microbial Control. Designers have focused considerable attention on reducing potential microbial amplification within ventilation systems. This has been done by selection of materials to minimize absorbtion of dirt and moisture that provide niches for microbial colonization. Fibrous insulations have been a particular concern. Control has been achieved by eliminating or reducing the use of exposed fibrous materials for acoustic control, by placing thermal insulations outside of ductwork, and by thoroughly sealing insulations from circulating air. There is a need for improved acoustic and thermal insulations for use in mechanical systems so that both insulation and air quality goals can be achieved (Levin 1990b). It is possible to fully cover insulations exposed to the air stream with mylar or another vapor barrier to minimize the potential for contamination.

Drip pans for cooling coils have been designed for positive drainage to eliminate standing water contributing to microbial growth. Ductwork, mixing chambers, and plenums are being designed for ready inspection and cleaning to control contamination. Humidifiers are now specified using "dry steam" rather than cold water sprays to minimize the likelihood of microbial contamination.

Standards Development. ASHRAE's recently-published revised standard for ventilation and indoor air quality is widely regarded as the most authoritative guidance for designers. However, its actual application is almost always limited to use of the prescribed quantities of outside air supply during design of building ventilation systems. Other important requirements such as outside air quality or the control of pollutant sources are generally ignored by HVAC system designers.

There is not universal agreement regarding the quantities of outside air supply required to maintain good indoor air quality. In fact, a very wide range of values for recommended or required outside air supply rates exists; the values appear partly to depend on the purpose of the indoor environment and the type of occupants anticipated in it. Thomas Lindvall of Sweden has presented a range of values for outside air supply rates from various authorities (Lindvall 1989). Table 5 lists various recommended and adopted ventilation rates.

[INSERT Table 5 HERE]

Currently there is discussion about revision of the ASHRAE standard and possible integration of thermal comfort criteria into a single, unified indoor environmental design standard. Such an integrated standard is not likely to be developed quickly, if at all. However, it is likely that the ventilation standard will be revised. The revised standard may include more detailed, specific guidance on acceptable contaminant levels and system design requirements.

Materials Selection and Specifications

The selection and specification of materials has received enormous interest, particular by designers who believe that source control is the most effective strategy for controlling IAQ. Some designers and authors have suggested reducing VOC emissions into indoor air by the careful selection and installation of building materials and furnishings. Some data are available to allow comparison of emissions from various products. However, no comprehensive set of data exists nor is it likely to in the forseeable future due to the large number of products and the variations in them over time. Some designers and their consultants have attempted to evaluate the toxic and irritating properties of emissions in order to choose less harmful or irritating chemicals (Levin 1989; Girman 1989). Table 6 lists the major steps in conducting such an evaluation.

[INSERT Table 6 HERE]

Materials emissions testing has beeen done by many research institutions and is beginning to be done by product manufacturers as well (Tucker 1990). Manufacturers are now adverstising products as "low-polluting," "non-toxic," "environmentally safe," and other such claims. (Levin 1990a).

While such trends are only in their infancy, significant changes are already occurring. Some designers are requiring the submission of emissions data by manufacturers before specifying or approving the product for use in the building. Included among the projects where such requirements are imposed are several major governmental projects that are "visible" to manufacturers. This has stimulated the development of testing in laboratories and the writing of standards for the conduct of such testing (Levin 1990a; Tichenor 1989; ASTM 1990).

Several authorities have proposed guidelines for maximum emissions for low-emitting materials and products (Seifert 1990). Some researchers are now planning to evaluate emissions in terms of various biological responses to them. (Tucker 1990). Others have used sensory responses of the anticipated occupants as a screening technique. In one case, the occupants of a home included two chemically sensitive children. After chemical screening, the children judged the products on the basis of brief exposures. (Salares 1990).

The maintenance requirements and projected life-cycle of materials are design considerations with important implications for indoor air quality. Too often these considerations are not adequately addressed during design. Some designers have developed materials and products that consider these factors with positive effects on indoor air quality. (Fredriksen 1990).

Controlling Emission Impacts Through Ventilation During Installation Ventilation procedures are specified to reduce the adsorption of VOC emitted from building materials during installation. These procedures involve one-pass, all outside air ventilation continously during installation of strong emitting materials. This reduces the contamination of "fleecy" materials by adsorption of the solvents and other volatile components of adhesives, caulks, sealants, plastics, and other building materials. Painting and carpeting are specified to be done under maximum ventilation conditions. Continuous ventilation during and after installation is required by designers. (Levin 1988; 1989; 1990a).

Problems remain in adeqautely characterizing emissions from the thousands of available products. Testing is expensive, time-consuming, and not standardized. Interpretation of results is difficult due to lack of knowledge regarding health effects. Trade-offs between the significance of toxicity and irritation must be determined. Nonetheless, the concern of designers is leading to the development of cleaner products and the elimination of some of the strongest emitters from the market. ((Levin 1989; 1990a).

During the coming years it is likely that materials marketing will become increasingly competitive while regulatory initiatives increase pressure on reluctant manufacturers. The likelihood is that some of the strong emitters will be replaced by other products. Researchers will increase our understanding of the factors necessary to select "clean," less harmful building products and furnishings.

<u>**Construction Process and Initial Occupancy**</u>

Design Documentation and Commissioning. Table 7 lists the major steps available to designers to control IAQ during construction and initial occupancy. Designers wishing to control IAQ now document design assumptions thoroughly and provide clear, detailed descriptions of building systems. This documentation is used to evaluate the completed construction during the "commissioning" phase before occupancy. The building is tested against the design criteria to assure its suitability for occupancy (ASHRAE 1989b). This procedure is rapidly being adopted by more designers and owners to provide assurance of good IAQ and other building factors.

[INSERT Table 7 HERE]

Special Ventilation. Designers have begun to specify extra ventilation immediately before and during initial occupancy of newly constructed or renovated buildings. All outside air, 24-hours per day ventilation is used to minimize occupant exposure to emissions from new materials and furnishings. Such extra ventilation also reduces the potential for under-ventilation by incompletely balanced HVAC systems often characteristic of new buildings.

A special procedure known as a "bake-out" has been used in many buildings, and som initial research results have been reported. The procedure involves raising building temperature for 48 hours or more while maintaining at least minimal ventilation. The elevation of temperature results in more rapid emission of VOC and a correspondingly reduced contaminant load. The research results indicate that the method has potential to reduce contaminant air concentrations, that the process is not a trivial one in terms c technical requirements, and that there are some significant additional costs associated with its use. It would appear that pre-treatment of materials prior to installation would b a more efficient approach for many materials. However, for adhesives, paints, sealants and other products applied in the field, it may not be possible to reduce emissions adequately in a reasonable time period without the use of a procedure like the "bake-out."

Initial Occupancy Period. Due to the presence of many newly-installed materials an furnishings, the initial occupancy period is often accompanied by the presence of strc emission sources. In order to control the concentrations of indoor air pollutants from these sources, ventilation protocols are modified. Ventilation systems are set to prov maximum outside air (up to 100% where possible) during operating hours to reduce airborne concentrations of VOC. Additional hours of operation are provided, sometimes continuously (24 hours/day) until emission levels have tapered off. This might be from three to six or eight weeks after installation. Buildings are thoroughly flushed before re-occupancy after any period of vacancy - evening, weekends, holidays (Levin 1988).

BUILDING SCIENCE RESEARCH NEEDS

In spite of a few examples of building design that consider indoor air quality, the majority of design professionals have little or no awareness of indoor air quality considerations. Neither codes nor legal actions have sufficiently changed to create the necessary awareness and changes in practice.

Part of the problem originates from the fact that there is inadequate communication of building science research results to design professionals. Ultimately, it is the building design professional's client who decides whether to address indoor air quality, especially where there are no regulatory or financial requirements to do so.

Information Needs

There is a long lag time in the translation from building science research and related fields into buidling design professional practice. In most instances, incorporation of the results from building science research is into codes, standards, and new products. Additional incorporation occurs through the retention of specialized consultants in new and emerging areas of practice. But economic and institutional factors slow the transfer process (Schon 1967).

Building design professionals do not normally read technical and scientific publications. Much of their technical information that does not come from consultants is provided by manufacturers and suppliers of building products and materials.

There is a general lack of information available to design professionals regarding indoor air quality. Architects and their consultants who might wish to incorporate low-polluting materials in their designs do not have avaialble to them clear, simple means to obtain information on products they might consider. They are not trained or qualified to evaluate "healthy" products; they must rely on some sort of industry standards for testing and labelling or rating system. They need information on the performance of products with respect to durability, life-cycle costs, maintenance requirements, and health effects.

Diverse Interests

There is a complex set of actors involved in the process of making and using buildings. Table 8 lists four major groups of individuals with different perspectives, needs, and relationships to the buildings they affect (or that affect them). Controlling energy consumption, indoor air quality, and other environmental factors involves the complex task of coordinating their diverse inputs and resolving differences in their needs.

[INSERT Table 8 HERE]

Need for a Theory of Building Ecology

The absence of a useful general body of knoweldge, theory, and practice regarding building-environment-occupant interactions is an impediment to developing the necessary professional design tools and practices to develop and operate low-pollution, energy-conserving buildings. Design professionals and facilities operators are not equipped to analyze buildings as dynamic entities with important impacts on occupants as well as a dependence upon the outside environment.

Borrowing from the approach in the biological science of ecology, we have suggested that researchers and practitioners develop a systems approach to understanding building-environment-occupant interactions. We have coined the term "building ecology" to describe this concept or approach to understanding buildings (Levin 1981). The concept requires application of a systems approach to understanding, designing, and operating environmental control systems in buildings.

CONCLUSION

Much progress has been made toward improving environmental quality and energy conservation through building design and operation. Site planning, architectural design, ventilation, materials selection, and commissioning have all made contributions. Yet there are still numerous technical problems challenging researchers and professionals alike. The next few years is likely to produce further improvements in indoor air quality by design.

An overall approach to building design involving consideration of the inter-relationship of the building, the larger environment, and the building occupants in a complex, dynamic system can contribute much to continued improvement of building environments by architects, engineers, and interior designers. This overall approach, called "building ecology," can also provide the foundation for theoretical advancements in the building design professions.

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Table 1 - Major phases and subcategories of critical building design control.

SITE PLANNING AND DESIGN
Ambient Air Quality
Local Source Control
OVERALL ARCHITECTURAL DESIGNS
Vehicle Access
Building Openings
Operable Windows
Pollutant Generating Activities
Envelope and Structural Materials
Basement Dehumidification
Smoking Lounges
VENTILATION AND CLIMATE CONTROL
Dilution by Outside Air
Air intakes
Exhaust Locations
Air Cleaning
Space Air Distribution
Heat Recovery
Microbial Control
Standards Development
MATERIALS SELECTION AND SPECIFICATIONS
Low-Emitting Materials
Preventive Installation Procedures
In-Place Curing
CONSTRUCTION PROCESS AND INITIAL OCCUPANCY
Design Documentation and Commissioning
Special Ventilation
Initial Occupancy Period
FUTURE TRENDS
Continuation and Improvement
More Building Design Professional Involvement

Table 2 - The major elements of IAQ control during site planning and design.

PRE-DESIGN SITE EVALUATION
- Analyze Regional and Local Ambient Air Quality Data
- Analyze Adjacent and Nearby Pollutant Sources
  - Vehicular Traffic
  - Industrial Sources
  - Commercial Sources
  - Agricultural Sources

Analyze Soil and Groundwater Sources
- Radon and Other Radioactive Decay Products
- Volatile and Semi-Volatile Organic Compounds

Determine Prevailing Weather and Wind Patterns
- Diurnal Variations
- Seasonal Variations

SITE PLANNING
- Site Selection for Suitability
- Building Location and Orientation
- Vehicular Circulation

LOCAL SOURCE CONTROL
- Landscape and Architectural Buffers
- Soil Depressurization
- Drainage
- Site Preparation and Imported Soils

Table 3 - The major categories of overall architectural design considerations.

Location of Vehicle Access
Separate from Air Entry Points
Building Openings Facing Clean Air
Consider Sources, Wind, Building Pressure
Operable Windows for Backup Ventilation
Occupant-Controlled for Comfort
Isolate Pollutant Generating Activities
Separate Rooms, Negative Pressure, No Recirculation
Durable Envelope and Structural Materials
Minimize Emissions, Maintenance, Refinishing
Basement Dehumidification, Pressurization
Prevent Microbial Contamination, Pests, Soil Gas Entry
Separate Smoking Lounges
Exclude Polluting Behavior from General Space

Table 4 - The major ventiation design considerations for good IAQ

Dilution by Outside Air Ventilation
    Outside Air Per Occupant (OA CFM/P)
    Outside Air Exchanges per Hour (OA ACH/H)
    Ventilation Based on Contaminant Source Strengths
    Direct Exhaust from Polluting Activity Spaces

Air Intake Locations, Design
    Avoid Plumes from Known and Suspected Sources
    Avoid Standing Water and Cooling Tower Drift
    Prevent Bird Roosting or Animal Entry at Intakes

Building Exhaust Locations
    Avoid Contamination of Ventilation Air Intake by Re-entrained Exhaust
    Increase Height and Distance from Air Intakes

Air Cleaning and Filtration
    Outside Air Meets Ambient Air Quality Standards:
        - Particles: Media, Electronic Filters
        - Gases: Chemisorption, Scrubbers
    Recirculated Air Meets Guidelines/Standards

Space Air Distribution
    Prevent/Eliminate "Dead Zones" and Stratification
    Deliver Ventilation to Occupant Breathing Zone
    Maintain Effective Pressurization Control
    Balanced Supply and Return Air Systems

Heat Recovery
    Energy Conserving Outside Air Ventilation
    Transfer Air for High Ventilation Rate Areas
    Use Heat Recovery Devices Where Practicable

Microbial Control
    Avoid Fleecy Materials in Air Stream including Ductwork
    Eliminate Standing Water in Drip Pans

Table 5. Various recommended and adopted ventilation rates (Lindvall, 1989).

(L/s)*	Basis or Recommending/Adopting Group
>0.3	2% CO_2 (respiration)
>0.5	1% CO_2 (performance)
>1	0.5% CO_2 (TLV)
>3.5	0.15% CO_2 (Pettenkofer Rule, 1858; body odor)
2.5	ASHRAE Standard 62-1981
3.5	Swedish Building Code 1980
4	Nordic Building Regulation Committee 1981
5 - 7	Berglund et al (body odor)
8	Fanger et al (body odor)
7.5	ASHRAE Standard 62-1989
5 - 10	Swedish Building Code 1988
10 - 30	Swedish Allergy Committee 1989
10, 20	Nordic Building Regulation Comm., preliminary 1989
16 - 20	Weber et al; Cain et al (Tobacco smoke annoyance)
14 - 50	Fanger et al (total odor)

* 1 Liter per second ≒2 cubic feet per minute

Table 6 - MATERIAL SELECTION & SPECIFICATION

Specify IAQ Concerns in Bid Documents:
- Health, Safety, and Comfort of Occupants
- Manufacturer Responsibility for Review and Assurance

Require Submittal of Product Contents & Emissions Tests

Select Low-Emitting Materials and Products

Criteria for Evaluating Emissions Data: Minimize
- Odorants
- Irritants
- Systemic Toxins
- Carcinogens, Teratogens

Specify Minimal Required Use of Adhesives

Minimize Use of Fleecy (High surface area) Materials

Utilize Preventive Installation Procedures

- Ventilation During and After Installation
- In-Place Curing: Ventilation, Bake-Out

Table 7 - CONSTRUCTION & INITIAL OCCUPANCY

- Prepare Design Documentation and Commissioning Plan
  - Document Design Assumptions
  - Document Systems Characteristics, Function
  - Plan Commissioning Process
- Special Ventilation
  - During and After Installation of Strong Sources:
    - All Outside Air, Continuous Ventilation
    - Seal Return Air Plenum, Ducts
- Commissioning Process
  - Complete Operation and Evaluation of HVAC System
  - Challenge System Under Full and Part Loads
- Initial Occupancy Period
  - All Outside Air Ventilation, Extended Hours
  - Respond to Occupant Complaints
  - Monitor Occupant Responses to Reduced Ventilation

Table 8 - Key Actors in the Building Process

Codes and standards organizations
Professional Associations
Industry and Trade Associations
Lenders
Insurers

Owners
Tenants
Occupants
Visitors

Designers (Architects, Engineers, Interior Designers, Consultants)
Product/Material Manufacturers and Distributors
Builders
- Contractors
- Tradespeople
- Equipment suppliers

Building Managers
Building Operators
- Janitorial or Custodial Staff
- Repair Personnel
- Maintenance Personnel
- Service Personnel

Contract Service and Supply Organizations
