PROTOCOLS TO IMPROVE INDOOR ENVIRONMENTAL QUALITY IN NEW CONSTRUCTION

Hal Levin
Center for Environmental Design Research
University of California, Berkeley

ABSTRACT

Practical procedures for identifying, evaluating and controlling potential sources of indoor air pollution have been developed for use in large, commercial building projects, covering every phase from site selection and design through construction and post-occupancy evaluation.

Site evaluation includes identification of on- and off-site air pollutant sources and the conditions that require their control. Design begins with evaluation of overall ventilation, lighting and thermal control schemes and includes systematic selection of building materials and furnishings. Construction procedures include provision of temporary ventilation, where required, to reduce levels of indoor air pollutants in the completed building. Modifications to furnishings and finish materials, where required, are incorporated in the construction documents issued to potential bidders.

Pre-occupancy assessment of ventilation system performance and indoor air quality are incorporated in the construction schedule and budget. Special ventilation system protocols are developed for the initial occupancy period. Air quality monitoring and subjective evaluation are used to guide the transition from special protocols to long-term, "normal" operation.

June 1987

Submitted for publication in

Practical Control of Indoor Air Problems, Proceedings of IAQ '87,
Sponsored by ASHRAE

PROTOCOLS TO IMPROVE INDOOR ENVIRONMENTAL QUALITY IN NEW CONSTRUCTION

Hal Levin
University of California, Berkeley

INTRODUCTION

Building sickness (also known as "tight building syndrome" and "sick building syndrome") has become increasingly common in new and newly remodelled buidings (Finnegan 1984; Stolwijk 1984). Additionally, a growing awareness of building sickness has increased the attention paid to occupant complaints of building-related irritation or illness. While the causes of the problems and the complaints associated with them are only partially understood, there is general agreement that a certain group of causal or circumstantial factors is frequently involved. These causal or circumstantial factors have been enumerated by many authors (Ammann 1986; Berglund et al 1984; Fanger and Valbjorn 1978; Molhave 1982, 1986; NAS 1981; Stolwijk 1984; Turiel 1979, 1985). They include elevated air levels of numerous chemicals, particulate matter including biological aerosols, and inadequate ventilation (Goromosov 1968; Levin 1981).

Working with architects, engineers, interior designers, and building owners' representatives, we have developed practical procedures for identifying, evaluating and controlling potential sources of indoor pollution. These procedures, developed for use in large, commercial buildings, cover every phase from site selection and design through construction and post-occupancy evaluation. Many of the procedures have not been sufficiently investigated to confirm their effectiveness, but we believe that generally they reflect a consensus among professionals and researchers who work on indoor air quality (Collins 1985; Levin 1986; Sandia 1982).

In a sense, many of the procedures described here are simply variations on normal professional design practices incorporating concern for indoor air quality. Most of the procedures are described from the perspective of the building design professions: architecture, engineering, and interior design. Some of the practices fall outside the direct control of the design professionals, but they can be recommended to building management, maintenance and operation personnel. It is also important that design professionals become aware of the operational considerations required to improve indoor environmental quality in order to improve building design (Levin 1986).

The major phases of a building project are divided in this paper as shown in Table 1.

SUGGESTED PROCEDURES

Project Planning Phase

Planning a building project involves programming; economic, space and functional feasibility studies; scheduling the project from design through occupancy; determining construction and long-term financing; and assembling the design team. Many of the factors affecting indoor air quality are determined by decisions made before the actual design process begins.

Programming. During the "programming phase," architect and client define the goals and objectives of the projected building, specify the spatial and functional requirements, and establish the criteria and standards to be used in evaluating alternative design proposals. Air quality and other indoor environmental performance standards can be explicitly set forth in programming.

During programming, occupant activities anticipated in the building should be identified in terms of their potential to generate indoor air pollutants or their sensitivity to indoor air pollutants. Industrial processes, laboratory activities, food preparation, printing, duplicating, copying, mailing, and other office-associated activities can be sources of significant indoor pollution. Architects can best choose air quality control methods for such functions when they are identified early in the project and adequate planning allows consideration of alternative control strategies. Space planning can separate incompatible functions, isolate pollution-generating activities, and buffer activities sensitive air pollution.

In many instances, details of the ultimate use cannot be determined prior to construction or occupancy, as in rental buildings. Therefore, provision must be made for a combination of flexible designs and limitations on occupant activities that will result in acceptable indoor air quality. Unused flexibilty designed into a building results in an unnecessary expense, but inflexibility, eliminating some potential tenants, might have unacceptable economic consequences for a landlord or building owner. Some compromise is usually necessary. Specifying the acceptable types of activities and range of environemntal control system requirements at the planning stage will increase the potential to accommodate both the owner's needs and the requirements for acceptable air quality.

Outline specifications are sometimes prepared during the planning stage to allow evaluation of the projected building's cost or value. Outline specifications prepared with conceptual design drawings should include air quality related performance criteria of the ventilation sys
tem, major materials, and furnishings. Consideration of indoor air quality at the earliest point in the process makes adequate consideration more likely during each phase of the project.

The Budget Process. It is important that indoor air quality be considered during the budget process. Failing to achieve acceptable indoor air quality in the completed building can have significant economic consequences. The architect (or other prime design professional) is responsible for designing within the client's budget and advising the client regarding the estimated cost of the project.

Architects' efforts to improve IAQ can be constrained by the reluctance of clients to commit the additional resources necessary. The important issues and considerations need to be articulated by the designer in order to allow the client to make informed decisions. Many building developers are not aware that early attention with front end expenditures can reduce or eliminate the negative economic consequences of post-occupancy IAQ problems.

The major budgetary considerations related to indoor air quality are (1) provision of adequate funds to acquire specialized services during design, construction, and initial occupancy, and (2) to provide sufficient time after the scheduled completion of construction to allow for thorough commissioning and testing of building performance.

Coordination of the Design Team. The architect serves as the lead designer who assembles the design team and orchestrates its work. Architects have ultimate responsibility for the design and for determining that the completed building fulfills the design intent. In order to fulfill his/her responsibilities, the lead design professional must obtain the services of specialized consultants appropriate to the particular project and to complement those of the architect's own staff. The design team normally consists of engineers, interior designers, specifications writers, specialized consultants, and construction experts. The team should include consultants with special competence in understanding and resolving indoor air quality issues. Some authors suggest that architects recommend to their clients that indoor air quality or indoor environmental consultants be retained on every building project.

The architect and the owner's representatives should develop a clear set of performance specifications as part of the direction given the mechanical engineer. In addition to the usual data on anticipated climate and acceptable indoor environmental conditions, outside air supply and ventilation efficiency should be specific elements of the directions given the mechanical engineer. Also, the means to be used to confirm the performance of the ventilation system in the completed building should be discussed and the agreed objectives pursued as part of the services of the mechanical engineer.

The architect's responsibility for the design consultants' work includes coordinating and integrating their various design inputs. Building construction and post-occupancy problems often arise from inadequate coordination of design consultants. Ideally, all of the critical members of the design team will assemble periodically to review progress and discuss concerns. The indoor air quality specialist should be part of the assembled group.

Site Evaluation. Architects and engineers are often called upon to evaluate potential building sites for their clients. Included in the criteria for site evaluation should be the potential impact of the site itself on indoor air quality, including climatic factors and local topography and buildings. Important considerations will be identification of on- and off-site sources of air pollutants and the various conditions that will require their control.

The sources of air pollutants might be adjacent or nearby stationary pollution sources, for example, exhausts from factories or from commercial buildings such as dry cleaning establishments or restaurants. The location of nearby roadways, parking lots, and garages and their motor vehicle traffic patterns might result in off-site pollution sources. Consideration should be given to variations in the potential sources over time including daily, weekly, and seasonal patterns.

The temporal and spatial variations in wind direction and velocity, traffic patterns, or emissions from industrial processes should be considered. The locations and forms of adjacent buildings might result in local wind patterns that cause re-entrainment of the planned building's own exhausts.

Previous land uses, such as agriculture or industry, might result in emissions from contaminated soil or groundwater as a potential indoor air pollutant source. Some examples of potentially significant sources might include wood preservation and treatment; solid waste handling, storage, and treatment; dry cleaning processes; leather, paint, or chemical manufacturing; refrigerated storage; gasoline stations; and agriculture. Even nearby building demolition can result in significant site contamination through release of building materials such as asbestos into air or into soil, which may remain on site or be back-filled onto it. If the prior history of the site is not known, it should be discovered before final site acquisition or design.

Valuable air quality and weather data are available from local air quality monitoring and regulatory agencies, National Oceanic and Atmospheric Administration monitoring stations, airports, harbors, and even certain resort and athletic establishments. Data on prior uses of sites may be available through historic building surveys or documentation, older fire insurance maps, municipal land use records, assessors' and recorders' files, and other state and local health, waste disposal, or hazardous materials control agencies.

A set of manuals for air quality considerations in residential planning was prepared for the United States Department of Housing and Urban Development in 1978. While written for the residential environment, the methods and procedures described there will be useful for any type of building. These manuals provide illustrative base maps, calculations sheets, and other aids to the preparation of a comprehensive assessment (Thulliier 1978a,b,c).

Design Phase.

Building design activity is usually divided into three phases: schematic design, preliminary design, and design development. During schematic and preliminary design, the basic building concept is devised and and placed on the site. During design development, the details of the design are worked out and specific materials, components or systems are selected.

Most of the elements designed during schematic and preliminary design are re-worked, refined, and detailed during design development and once again during the production of working drawings and specifications.

Schematic Design. During this phase of the work, the conceptual framework of the building is articulated. Major spatial and functional relationships, general sizes and locations of important building elements, architectural and engineering concepts, and relationship of the building to the site and its surroundings are all determined. Conceptual approaches to ventilation and thermal control (as well as many other critical building design decisions) are considered and tentatively resolved during the schematic design phase. The schematic design is developed to the point that a recognizable building form and general materials and systems are articulated in drawings, models, and written descriptions.

Preliminary Design. The building design includes siting, orientation, configuration, and interior layout. The basic characteristics of the building, its size, shape, exterior shell, systems, and materials are determined during the preliminary design work. Of particular importance to indoor air quality are the selection of major environmental control strategies including illumination, ventilation, and thermal control. This is the time to consider the implications of such choices beyond the conceptual level and to evaluate the trade-offs among significant alternative designs. This often involves preliminary calculations of loads and the capacities of systems designed to handle them. Also important to indoor air quality are the selection of major building materials and equipment other than for environmental control. The selection of these building components can have a large and lasting effect on indoor air quality and, therefore, should be done with adequate consideration of their IAQ impacts.

Site planning and site design are an integral part of the design process. If pre-design site assessment has not been completed, the design phase should begin by assessing ambient air quality and potential external sources of indoor air contaminants. The process described above under the "Site Evaluation" should be followed. By assembling and reviewing weather, air quality, soil, and traffic data available from local, state, and federal agencies, architects and engineers can develop reliable information to identify and evaluate the potential sources, characteristics, source strengths, and points of origin for air contaminants. This information can then be used during design to identify and assess various alternative design solutions to address potential sources of indoor air pollution.

Solutions might include locating the building on the site as far removed as possible from pollutant sources, or out of the normal wind patterns coming from pollutant sources. Air intake locations for both mechanical and natural ventilation systems can be eliminated or minimized where outdoor air pollution plumes would be expected. Vegetation or other screens can be utilized to form a barrier to particulate matter or to adsorb certain chemicals. Vegetation might be particularly effective in protecting a building from motor vehicle pollutant sources.

Building design solutions might include locating air intakes remote from pollution generation points or areas, creating architectural barriers to direct polluted airflow away from building air intakes, providing appropriate filtration for identified pollutants, or locating air-pollutant-sensitive elements away from exterior sources. Selection of window and door systems might include consideration of their designed protection against outside infiltration and the oudoor air pollutants that might pass through the openings. Designers can also consider the impact of the building fabric on identified pollutants, which might interact physically, chemically, or biologically with the building fabric or systems.

Design Development. During design development, the preliminary design is made more specific and detailed. Engineering calculations are made. Exact sizes of components of the building are fixed. Choices of finish materials and equipment are considered and alternatives are evaluated. Product research is done by use of catalogs, data sheets, product design manuals, and by contact with technical representatives. During this phase of the work, there should be continued consideration of indoor air quality implications of alternative design options.

Building Ventilation. Ventilation's role in controlling air quality in buildings is significant. The designed air exchange rate, the choice of constant or variable volume air supply, the use of pneumatic or electronic controls, the general location of intakes and exhausts for the building and each space within it exemplify important indoor air quality determinants. The best solution will vary from project to project. Certain considerations are fundamental to the selections that will result in acceptable indoor air quality (NAS 1981; Turiel et al. 1983; Turiel 1985).

Designers should consider the following important factors in designing building ventilation systems:

1. The quality and quantity of outside air supply under various climatic conditions and HVAC operational modes;

2. Supply air conditioning (filtration, humidification, thermal control);

3. Air distribution system type, materials, equipment, and controls;

4. Operation, maintenance, and monitoring of ventilation systems.

Architects should review the engineer's efforts to optimize indoor air quality, comfort, and the ventilation system's operational cost. They should consider the distribution of costs between construction and operation and between building management and tenants.

Thermal Control. Occupant comfort, air pollutant emissions into indoor air from building materials and furnishings, occupant perceptions of air quality, and pollutant removal rates or dilution rates are affected by air temperature. Thermal regulation systems can generate, exacerbate, or reduce indoor air pollutants. Where ventilation systems are used for thermal control, designers should consider temperature and air quality together.

Ventilation Efficiency. The decisions made at this stage will have significant impacts on ventilation efficiency, which can indicate the potential of the ventilation system to provide acceptable indoor air quality in the breathing zone. Design and operating conditions affect ventilation efficiency, which varies significantly among buildings, within buildings, and even in a single building. If ventilation efficiency measurements in both laboratory and field situations reported in recent years are representative of actual conditions, then far less than the designed ventilation rate, often between 50% and 75%, is typical (Persily 1986; Seppanen 1986).

Thus, actual ventilation rates in the breathing zone require that both the outside air supply volume at the diffusers and the ventilation efficiency be specified as design conditions. The combination will yield a performance specification for air exchange in the breathing zone. Alternately, a ventilation efficiency rate can be assumed and its inverse applied as a correction or safety factor to the desired supply air volume in the breathing zone to obtain the required supply air volume at the diffuser. Regardless of the approach chosen, building designers can adjust the design to provide the required air supply volume by joining ventilation efficiency to air exchange or outside air supply quantities.

Architects can improve ventilation efficiency by carefully locating and sizing air supply and return registers within the conditioned space. This might include architectural decisions to locate supply registers in the floor or walls rather than the dominant current practice of locating them in the ceiling. Or, air could be distributed under floor (more easily under raised floors) and then through easily connected and relocated risers to individual work stations. There, an occupant-controlled diffuser at desktop height can be adjusted for volume and direction of flow. This is just a single example of innovative design approaches that might emerge from efforts to improve ventilation efficiency. In fact, this concept has already been implemented in at least one high-rise office building (Doubilet and Fisher 1986).

During design, measurement of ventilation efficiency in a mockup or model of the designed space can assist in adjusting critical design variables to improve HVAC performance. This procedure may be used to determine appropriate heights for free-standing partitions or for determining the impact of elevating the bottoms of such partitions above the floor. It may result in different configurations of low and high partitions to improve air distribution and movement patterns. Testing in mockups can be used for determining optimal ceiling heights or diffuser heights above the floor. Tests can be used to improve airflows due to relationships of supply and return air registers and the volumes flowing through them. Performance specifications can be developed in the mockups to allow contractors and air balance companies to use more discretion in achieving them in the field. Measurement in the completed space can be useful in determining actual HVAC system performance.

Production of Contract Documents

Production of working drawings and construction specifications, as they are often called, presents architects with many opportunities to make detailed decisions to implement earlier design concepts. Specific designations of materials, equipment, and layouts are developed in the preparation of the contract documents. Products are considered and selected. Here architects can exert enormous influence on clients as well as on the providers of the products. Architects can require potential product suppliers to develop and provide bettter information on the chemical contents of their products and their performance (such as emission rates of critical substances). They can provide clients with clear analyses of the air quality implications or trade-offs in important materials or equipment selections. Specifications can include performance requirements, such as ventilation efficiency of HVAC systems or chemical emissions of major finishes and furnishings.

Interior Design. Interior design and use of space can have significant impacts on indoor air quality and comfort. The interior space layout and uses should be considered in terms of the pollution-generation and pollutant-sensitivity of occupant activities, pollution-exposed areas, and practical measures to mitigate contamination. Special activities that will generate pollution (e.g., printing, duplicating, mailing, food preparation) should be identified. Available alternatives to mitigate the impacts of occupant-generated pollutants should be described, analyzed, and recommended.

Building Materials Selection and Specification. Materials employed in the construction of the building can have significant impacts on indoor air quality. Many materials are known emitters of toxic or irritating chemicals. Failure to evaluate and carefully select materials can result in unnecessary, costly, and troublesome contamination of indoor air (Molhave 1982, 1986; Sheldon 1986; Stolwijk 1984).

Architects can evaluate candidate products and materials in terms of their projected chemical emissions rates and the chemicals' known effects on occupants. Important materials are those whose use is extensive, whose emissions are large, either short- or long-term, and whose volatile contents are known toxins or irritants. Some of these materials are carpet systems (carpet, pad, and adhesive); flooring systems (floor covering, subfloor or underlayment, and adhesives); ceiling tiles; wall covering systems; thermal insulation, fireproofing, caulking materials, and sealants exposed to indoor air; and ductwork and additional materials in contact with the supply or recirculation air stream. In addition, furnishings and equipment within the scope of architectural services should also be evaluated. (A detailed description of the process for evaluating materials may be found in a companion paper.)

Architects can develop supplemental instructions to issue to potential vendors with the bid documents. These instructions can require submittal of complete information on the components of the products being offered. The information thus obtained can be used for product and materials evaluation based on published information or lead to further inquiry with the component suppliers.

On the basis of the review described above, architects can evaluate bids and submittals and recommend selection, further evaluation, or testing. By review of product literature and published data, architects can determine whether candidate products produce an unacceptable level of air contaminants. Negotiation with suppliers can result in implementation of measures to limit the toxic or irritating chemical content or emissions of selected products by changes in design or manufacture.

To reduce source strengths in the completed building, performance specifications may be issued with respect to material contents, emissions rates, design details, packaging, shipping procedures, and installation. Modifications to furnishings and finish materials, where required, are incorporated in the construction documents issued to potential bidders.

Loading an enclosed structure with products that release large quantities of chemical pollutants into the air results in contamination of the building fabric. Many of the chemicals, particularly the semivolatile ones such as pesticides and polychlorinated biphenyls (PCBs), are adsorbed on the surfaces of building materials and furnishings; they can then be re-emitted into building air later, during occupancy. The length of time when a newly finished or furnished building contains elevated levels of construction-derived chemical contaminants is thus extended.

Most products receive limited exposure to the environment after manufacture. They are usually packaged and prepared for shipping or storage promptly. Therefore, the packaging, shipping, and installation process presents many opportunities to limit the contribution of interiors materials to deteriorated indoor air quality in the completed structure. Architects can specify procedures to reduce the amount of unstable chemical contaminants entering the building or building air. These include packaging and shipping procedures, unpacking and loading into the building, installation practices, and building ventilation during delivery and installation in the building. Maximum exposure to air circulation and warming prior to entering the building will decrease negative indoor air impacts.

Modifications of shipping container designs and packing can allow for more air circulation without significantly increasing exposure to soiling. Storage facilities often lack adequate ventilation to permit much off-gassing. By increasing air movement in warehouse facilities, certain products may be allowed to emit a significantly greater portion of their unstable chemical content. Carpets and other products can be exposed to elevated temperatures, steam, or air circulation in production facilities prior to packaging in order to reduce emissions when unpacked in the completed building. Even trucks can be modified to increase the off-gassing by providing for more air movement and air exchange during transport.

Installation of Furnishings. Many newly manufactured building materials and furnishings emit a major portion of their lifetime chemical emissions during the first few hours, days, or weeks they are exposed to the environment. Air circulation at their surfaces is critical to the release of chemicals. Elevated temperature, humidity, and exposure to ultraviolet light can also accelerate off-gassing (Tichenor 1986; Tucker 1986). Therefore, the quantity of chemicals emitted into building air can be reduced by exposing materials and furnishings to environmental conditions prior to their loading into the building. This involves a number of logistical considerations, such as protection of carpets and furnishings from soiling after packaging and protective wrappings are removed.

Construction Process

General Considerations. The construction process offers many opportunities to observe and correct problems before the building is completed and occupied. The review from an environmental quality ensurance perspective of change orders, shop drawings and other submittals, and of installations in the field can be cost-effective in avoiding construction and occupancy delays, call-backs, and problems in the occupied building.

Implementation of methods and procedures available during construction can limit the pollutant load in the completed structure. Phasing and scheduling of activities like installation of carpet and ceiling tile, temporary ventilation, and control of strong air pollutant source materials entering the enclosed structure can be used effectively to reduce airborne pollutant levels during construction. Excess levels during construction will extend the time after completion when levels will be elevated.

Properly completing construction close-out, commissioning the new building, and training of operating personnel will further reduce problems in the newly completed and occupied building. Attention to indoor environmental quality during this phase of the project is a frequently neglected and critical determinant of the building performance.

Change Orders, Shop Drawings. Changes made and details supplied by contractors or designers during construction can significantly impact indoor air quality. These changes are often made in response to previously unanticipated problems or events during construction. The change order and shop drawing approval process often fails to ensure that the new detail meets the design intent and the established performance criteria.

Architects and their consultants can review, evaluate, and follow-up on change orders, field orders, and shop drawing approval requests for items determined significant to indoor environmental quality. These might include HVAC system components, insulations, sealants, finish materials, and furnishings, among others. The list of items requiring special attention with respect to IAQ should be identified by the architect and the HVAC consultant.

Temporary Ventilation. The provision of temporary ventilation during construction can control air levels of chemicals that can contaminate building materials. Large surface area materials, such as thermal, sound, and fire insulations, textured plaster, wood, carpets, or fabric, can become "sinks" for chemicals as their air levels increase. Subsequent re-emission can cause elevated contaminant air levels in the completed structure. This increases the risk of occupant complaints or health problems and may require special ventilation to control contaminant air levels, an added but avoidable cost.

The architect can review the construction schedule and phasing to determine the need for temporary ventilation. Temporary ventilation recommendations described here are not intended as a substitute for oversight or review of compliance with labor laws applicable to construction workers. The purpose is solely to reduce the pollutant burden in the completed structure by mitigation measures during construction. Specific details can be made part of the general conditions of the construction contract. Review of construction documents and consultation with the client can help the architect determine feasible means of providing temporary ventilation. Analysis of available alternatives and recommendations for temporary construction ventilation procedures and schedule can also be specified.

Progress Inspections. Inspections by owner's agents and architects tend to focus on compliance of construction with contract documents, scheduling issues, and determinations related to field orders. The intent or function of the building materials or equipment is often overlooked and the result is poor building performance. If the performance goals and criteria are kept in mind, the architect's site visits can be useful in identifying construction or design problems that will affect indoor air quality. Architects can identify critical components to be inspected during construction and develop a plan of construction site monitoring or quality control related to indoor air.

Air balance work determines air velocities or static pressure changes to compute airflow volumes at various HVAC locations. This is done under full flow conditions to adjust the flows of individual HVAC system components to design specifications. Air balancing does not reliably estimate the delivery of air or removal of pollutants in the breathing zone, nor does air balance work verify the performance of the system under heating or cooling load. Architects can require that determinations of the systems performance under load and ventilation in the breathing zone be part of the HVAC balance and final approval process. (See the discussion of ventilation efficiency above.)

Commissioning Phase.

While increased attention has focused on the commissioning process recently, time and economic constraints often limit the implementation of good practice. Many indoor air quality problems are probably due to false economies in the commissioning phase. It is during this period that the building owner can best determine whether the product (the completed building) represents what was contracted for with the prime design and prime construction contractors. Contract documents should specify both the procedures to be used to ascertain this conformity and the means for resolving conflicts.

Architects should review and analyze the effectiveness of training programs included in control system or HVAC equipment construction contracts. This includes an evaluation of materials, equipment, and procedures used in training. They should also evaluate the preparedness of operating personnel to perform routine and extraordinary tasks required of them in the new building.

Architects are responsible for inspection of construction, approval of payment to contractors, and for determining the "habitability" of completed structures. Too often, indoor air quality problems occur or begin due to premature occupancy of completed structures. By requiring evidence that a building's ventilation system is fully functional and that air quality is acceptable prior to initial occupancy, architects can improve IAQ. This can be accomplished through "performance testing" during or immediately after the "commissioning" of the completed building.

Initial Occupancy.

Initial occupancy can be the most difficult period for maintaining acceptable indoor air quality. Problems arise from off-gassing from new materials, an occupant population that has been stressed by a recent, sometimes reluctant move, incomplete or inadequate air balancing, and malfunctions in newly commissioned air handling or control equipment.

The initial occupancy period can be very useful for identifying construction problems and initiating corrective actions before warranties expire. A responsive building management approach to complaints can create positive occupant attitudes toward the building and the building management. Attitude and perception play as significant a role as physical reality in determining occupant physiological and psychological responses.

Architects and engineers can assist building owners and operators during the initial occupancy period by recommending provisional ventilation system operating protocols that maximize outdoor air supply and hours of operation and minimize operating temperatures. They can also recommend procedures for quick and economical evaluation of indoor air quality including objective (instrumented) methods and subjective, systematic methods (inspections, rating systems, and questionnaires).

Air quality monitoring and subjective evaluation are used to guide the transition from special protocols to long-term, "normal" operation (see discussion in "The Evaluation of Building Materials and Furnishings for a New Office Building" elsewhere in this volume.

On-going Operations

HVAC Maintenance. Many indoor air quality problems have resulted from inadequate or inappropriate maintenance of HVAC systems. Biological aerosols implicated in cases of building-related illness result from inappropriate HVAC maintenance. Architects and their consultants should review the manufacturer's recommended HVAC maintenance program and suggest improvements as required.

Building Maintenance. Some indoor air pollutants come from building maintenance materials. Examples include floor waxes, furniture polishes, carpet shampoos, and washroom disinfectants. Maintenance practices and schedules can exacerbate or minimize the contamination of occupied spaces. A careful review of maintenance plans can screen potential indoor air quality problems and reduce or eliminate many of them. Volatile chemicals should be minimized, and their application should occur when buildings are vacant, where possible, with good ventilation and maximum time until normal occupancy recurs.

Pest Control. Insecticides, fungicides, and rodenticides, while useful in controlling pests, can cause serious indoor air quality problems through misapplication or inappropriate timing of application. Careful planning and monitoring can avoid unnecessary problems while maximizing the benefits of pest control applications. Architects can consider minimizing the need for on-going pesticide applications by selection of materials and construction details during design. Examples are materials not subject to attack by micro-organisms and design details that do not provide locations for pests to hide, colonize or move about.

Evaluation of completed buildings offers an excellent opportunity for architects and building owners and operators to learn from their prior work. Post-occupancy evaluation, as it is called, is rarely done. The building industry can learn how to improve indoor air quality by studying the impacts of different design approaches on subjectively and objectively measured IAQ in completed buildings. Longitudinal studies, including surveying attitudes and opinions of future or prospective building occupants prior to occupancy and then at various stages after occupancy, can provide extremely useful information on occupant perceptions. Relating subjective evalutions to indoor air monitoring or ventilation system evaluations can assist building designers and developers to achieve more satisfying and economic indoor environments.

CONCLUSION

Architects, engineers, interior designers and building owners, managers and operators can make substantial improvements in indoor air quality. Many procedures can be applied during a building project as modifications of normal practices. By approaching every phase of the building process with concern for indoor air quality, the design, construction and operation of the building can be modified to reflect the understanding now available from indoor air research. Researchers can enhance the efforts of architects and others to improve indoor air quality by focusing research on design issues and by communicating research results to the design and construction community.

REFERENCES

Ammann, H.M., M.A. Berry, N.E. Childs, and D.T. Mage, 1986. "Health effects associated with indoor air pollutants." Proceedings of IAQ'86, Managing Indoor Air for Health and Energy Conservation. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Berglund, B., T. Lindvall, J. Sundell, eds. 1984. Indoor air, Volume 1: Recent advances in the health science and technology. Stockholm, Sweden: Swedish Council for Building Research.

Collins, K. and H. Levin, eds. Indoor pollution; the architects' response. Washington, D.C.: American Institute of Architects, 1984.

/

Doubilet, S. and T. Fisher. 1986. "HongkongBank: The systems," Progressive Architecture. 67(3) March 1986. pp. 100-107.

Fanger, P.O. and O. Valbjorn, eds. Indoor climate; effects on human comfort, performance, and health in residential, commercial, and light-industry buildings. Copenhagen: Danish Building Research Institute.

Finnegan, M.J., C.A.C. Pickering, and P.S. Burge. 1984. "The sick building syndrome: prevalance studies. British Medical Journal 289(8 December): pp. 1573-1575.

Goromosov, M.S. 1968. The physiological basis of health standards for dwellings. Geneva: World Health Organization.

Levin, H. 1981. "Building ecology". Progressive Architecture, 62(4), pp. 173-175.

Levin, H. 1986. "Indoor pollution research and its applications in office building development and operation," The Changing Office Environment. Washington, D.C.: The Urban Land Institute, pp. 271-284.

Molhave, L., I. Andersen, G.R. Lundqvist, and O. Nielsen. 1982. "Gas emission from building materials - Occurrence and hygienic assessment." SBI Report 137. Copenhagen: Danish Building Research Institute.

Molhave, L., B. Bach, and O.F. Pedersen. 1986. "Human reactions to low concentrations of volatile organic compounds." Environment International, 12(1-4): pp. 167-176.

NAS, 1981. Indoor pollutants. Washington, D.C.: National Research Council.

Persily, A.K. 1986. "Ventilation effectiveness measurements in an office building." Proceedings of IAQ'86, Managing Indoor Air for Health and Energy Conservation. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Sandia National Laboratories. Indoor air quality handbook for designers, builders and users of energy efficient residences. Albuquerque, New Mexico: Sandia National Laboratories, 1982.

Seppanen, O. 1986. "Ventilation efficiency in practice." Proceedings of IAQ'86, Managing Indoor Air for Health and Energy Conservation. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Sheldon, L.S., K.W. Thomas, and R.H. Jungers. 1986. "Volatile organic emissions from building materials - Results of preliminary headspace experiments" Research Triangle Park: Research Triangle Institute.

Stolwijk, J.A.J. "The sick building syndrome". Indoor air 84, Vol 1. Stockholm: Swedish Council for Building Research, 22-29.

Thuillier, R.H. 1978a. Air quality considerations in residential planning Volume 1, Guide for rapid assessment of air quality at housing sites. Washington, D. C.: United States Department of Housing and Urban Development.

Thuillier, R.H. 1978b. Air quality considerations in residential planning Volume 2, Manual for air quality considerations for residential locations. Washington, D. C.: United States Department of Housing and Urban Development.

Thuillier, R.H. 1978c. Air quality considerations in residential planning Volume 3, Scientific support and documentation. Washington, D. C.: United States Department of Housing and Urban Development.

Tichenor, B.A., and Mason, M.A. 1986. "Characteristics of organic emissions from selected materials in indoor use." Presented at the Air Pollution Control Association Annual Meeting, Minneapolis, MN. June 1986. Paper No. 86-16-5.

Tucker, W.G. 1986. "Research overview: Sources of indoor air pollutants." Proceedings of IAQ'86, Managing Indoor Air for Health and Energy Conservation. Atlanta, Ga.: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

Turiel, I., C.D. Hollowell, R.R. Miksch, J.V. Rudy, R.A. Young, and M.J. Coye. 1983. "The effects of reduced ventilation on indoor air quality." Atmospheric Environment. 17:(1) pp. 51-64.

Turiel, I. 1985. Indoor air quality and health. Stanford, Calif,: Stanford University Press.