Indoor Environ 1993;2:285–290

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Improving IAQ through Healthy Building Envelope Design and Systems Selection

Key Words
Healthy buildings
Building envelope design
Building materials selection
Design guide

Abstract
A simple systematic guide for architectural practice is proposed in the form of an IAQ-based design aid that can be utilized when decisions regarding the selection of envelope materials and energy systems are made. It is intended to be the first step towards the effective bridging of the existing gap between IAQ information and the architectural profession. The proposed guide is in a written form as well as a simple computer hyper-text and is intended to be a quick reference for obtaining direct information on types of pollutants associated with each finish material, health risks, and possible alternative materials with less polluting impact on indoor air.

Introduction

Architects do not have immediate access to a design-related, comprehensive information system on the IAQ aspects of the various building components, systems and materials. A resource is needed which brings together the relevant information in one easily accessible source, in a form that is modular, expandable, and usable by architects, as well as being easily updatable. Building materials and energy systems were selected as two representative modules in this paper due to their importance.

One of the essential measures to improve IAQ that has received little attention is the architectural selection of building materials based on their pollutant levels and potential health risks. Virtually any material with a non-metallic composition has some potential for containing chemical compounds that can either emit gases or evaporate from its surfaces and get into the air. The choice of thermal energy systems for heating and cooling, based on their potential IAQ implications, has also received little attention. The choice of the mode of heating or cooling has been found to affect indoor air quality [1]. Currently, no building codes or standards exist for safe levels of indoor air pollutants and contaminants. The United States Environmental Protection Agency (USEPA) set ambient air standards in 1970 under the mandate of the Clean Air Act, but there is disagreement on what the levels should be for indoor air. Further toxicological and epidemiological data are needed before levels can be set and used [2]. Building ecology is an important aspect of the overall building design process. The lack of air quality-conscious building designs increases the chances of creating unhealthy indoor environments. The intensity of airborne pollutants from building materials increases with reduced ventilation for the purpose of saving energy. Elimination of potential pollutants through proper selec-

Accepted:
May 7, 1993

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1016–4901/93/0026–0285
$2.75/0

tion of building materials is effective. Unhealthy environments could be easily created particularly in the absence of acceptable ventilation. The off-gassing and emission of vapors and particles from building materials in one zone of a multizone building may readily reach other zones through the building's ventilation and air circulation systems.

When deciding on the most appropriate building materials for a building envelope, architects must take into consideration the level of pollutant output from materials, the possible health risks involved, and the environmental impact of the selected energy system.

In recent years, an increased concentration of different indoor contaminants has been found to be excessively high in many randomly selected buildings. Indoor pollution levels often exceed standards set for outdoor air [3]. The major sources of indoor air pollution in buildings are: polluted outdoor air, indoor materials, indoor combustion by-products and indoor biological contaminants [4]. The problem of polluted outdoor air can be reduced through architectural design by avoiding heavily polluted areas for air intake vents, such as away from exhaust vents, loading docks, heavily traveled streets and busy intersections, and by filtering the air as it enters the building. An architect's major contribution to the creation of healthy indoor environments is to eliminate or at the least reduce any possible indoor contaminants through the appropriate selection of building envelope components and materials.

Current surveys indicate that up to 90% of the typical person's time is spent indoors [5], while, in cold climates, it is estimated to be 93% [6]. The combination of increased levels of contaminants and an increased length of exposure create a situation in which the health of occupants is affected and indoor air pollution complaints result. Complaints about the quality of the indoor environment have increased in the past decade, mainly among the occupants of new or newly renovated buildings. The term 'sick building syndrome' has been coined to describe some such problems. A survey by the USEPA ranked indoor air pollution as a greater health threat than both hazardous waste sites and outdoor air pollution [7]. Currently, research is conducted on the various factors that affect IAQ, such as ventilation rates [8], air filtering and air movement [5], the sources of pollutants [9–11], and mitigation strategies to eliminate, contain or dilute the offending pollutants [2]. Physical and psychological testing are also being used to determine the role of such aspects as light quality, stress and workstation comfort on overall response to the indoor environment [12]. Although these approaches propose solutions to the different indoor air problems, they rarely address their interdependency in an integrated holistic manner.

Since the late 1940s, there has been a proliferation of synthetic substances which release various chemical gases and particulates into the indoor air [7]. The architect has a responsibility to be knowledgeable about which substances are potentially harmful and ways to avoid them whenever possible. Only recently has the cataloging of materials as potential sources of indoor air pollution picked up momentum [13]. One attribute of a 'healthy' building is the use of relatively low pollutant-emitting building materials and finishes [14]. Generally speaking, the architect is in control of the selection of the materials and thermal energy systems for a building. Hence, the architect becomes a logical target for legal action over IAQ problems. Lawsuits against architects are often based on negligence, misrepresentation, fraud, or the breach of express or implied contract [2].

Controlling Indoor Air Quality through Design

A void exists between the IAQ research information and those in the variety of disciplines who could benefit from it. A selection guide can assist architects in the selection of nonpolluting building materials, components and systems and ultimately allow building design to control IAQ. Currently there is no reference of this specific nature and purpose available for professional architectural use. Indoor finish materials and energy systems are considered significant factors influencing IAQ over which architects have the most control. The concept of this guide intends to show a way to bring together some of the widely scattered research and technical information into a single technical source to be used as an architectural reference guide for choosing indoor finish materials based on their short- and long-term effects on the quality of the indoor air. It presents a simple approach for the utilization of current published research as the basis in identifying the significant factors that need to be known in order to evaluate indoor finish materials from an IAQ perspective. The guide intends to be concise yet sufficiently comprehensive, design-oriented yet easy to understand, and simple to use. Materials and thermal energy systems are among the primary contributing factors to indoor air pollution. Figure 1 shows these two factors along with other major factors that affect the IAQ.

Utilizing IAQ Design Knowledge

There are at least two other parallel efforts being made in the US that will help to bridge the gap between IAQ research findings and design practitioners. Although the information on indoor finish materials is currently not available in one place, the American Institute of Architects has begun the process of making a wide array of environmental information available to architects in the Environmental Resource Guide (ERG), part of which addresses the environmental and health implications of various materials, but does not cover thermal energy systems directly at this time. Only two materials to date, aluminum and particle board, have been researched and that research published in the ERG. Generally, the primary information is still scattered throughout various research publications.

The USEPA is developing a series of documents summarizing the available information on building materials and products brought into homes and office buildings as potential sources of indoor air pollution. The first document, a catalog of materials sources of indoor air pollution was completed in 1990. The additional portions of the completed handbook, information on the chemical constituents of these materials and emission rates of chemicals out-gassed from these products, will constitute a multiyear project. The current USEPA efforts are on the design of an organizational scheme and format for presenting information in a logical manner for the intended user groups which will include consumers, homeowners, designers and industry [13].

Unlike the ERG and USEPA efforts, the present work focuses on serving as a guide which would allow architects to obtain IAQ information on indoor finish materials. The accessibility of the information in a design-applicable form will promote the incorporation of the research findings into the architectural practice. The prime focus of the present study is the indoor finish materials (those materials that come into direct contact with the indoor air). All of these efforts are additional steps in promoting building ecology, which emphasizes the interrelationships of all of the components and factors of a building, including the larger environment and the building occupants, as part of a complex, dynamic system [13]. Most building design professionals give little consideration to IAQ issues. Part of the problem is the inadequate communication between building science researchers and design professionals [15]. The present study is only an example to show the usefulness of having the proposed guide available to architects. Other areas such as ventilation as a strategy for minimizing IAQ problems is a field of study in itself. Further, although ventilation plays a major role in IAQ problem mitigation, reducing pollution at the source is the focus of this reference guide.

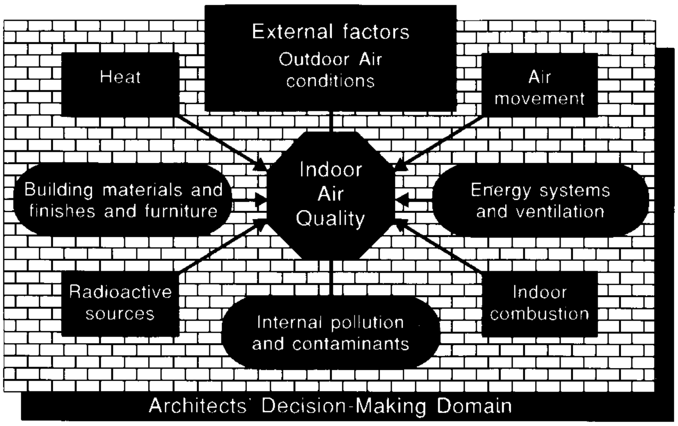

Fig. 1. Major factors affecting the IAQ.

Guide Logic, Methodology and Organization

Current, pertinent information on indoor finish materials and energy systems for architectural design use were brought together in a single source. A number of logical steps were followed to find and document the desired information: (1) identification of the possible sources of information, (2) assessing the information and obtaining the design-relevant data, and (3) compiling that information into a usable form for architects to allow them to consider the IAQ implications of the indoor finish materials and thermal energy systems that they are specifying. The guide is not intended to provide recommendations as to the 'best' choices of materials, but rather to provide information on various indoor finish materials and thermal energy systems to allow an architect to weigh the IAQ factors when choosing the materials and thermal energy systems for a particular project.

The emphases in the organization of the guide are: (1) providing only the information that is applicable to architectural design decision-making, (2) ease of use, and (3) presenting information in readily accessible forms. Since new information is constantly being made available, the guide has also been created to be easily updated. The hypothesis behind the proposed organization of the guide is that research data can be cumbersome to use in the architectural practice since it generally contains technical information on testing procedures, testing data and analysis, analysis of the results, as well as research results. Three ways of accessing the information were established:

(1) information in one-page summaries of each of the indoor finish materials and each of the thermal energy system types which include: (a) general information, (b) pollutants, (c) health effects, (d) alternatives and techniques for use and (e) references;

(2) a table that summarizes the health, pollutant and alternatives information in a comparative manner; and

(3) a HyperCard computer program in which the information can be accessed by material, energy system or pollutant. In this way, an architect can access the information in the manner that is most appropriate for the application in question.

Standards are currently being adjusted to provide higher air change rates (e.g., ASHRAE standard 62-1989 by the American National Standards Institute in June 1991 [16]). This standard specifies a ventilation rate increase to 15 cubic feet per minute (cfm) per person (up to 60 cfm per person) up from a previous minimum standard of 5 cfm. Chemical pollutants that can cause health problems indoors can potentially do the same outdoors [17], although the concentrations here would be much lower.

Major Subjects in the IAQ Guide

Twenty different finish materials that are most common are represented in the guide; viz., concrete, particle boards, plywoods, carpets, tiles, resilient flooring, wood, gypsum boards, plasters, acoustical ceiling tiles, plastic laminate, wall coverings, doors, windows, paints, varnishes, stains, adhesives, sealants and caulking. The energy systems covered include, forced air heating and cooling systems, electric convective heaters, heat pumps, wood stoves, fireplaces, electric baseboard heaters, hot water radiators, and in-floor hot water systems.

Finish materials may be important because of the emission of pollutants. Emission factors per unit area of material can vary by a factor of many thousands from one material to another. The emission rate depends on how much material is present and the conditions of the indoor environment. These, along with the duration of the emission, become the important factors in the overall amount of pollution and the effect on the building occupants.

Synthetic materials are increasingly utilized for indoor finishes, furnishings and construction materials, The chemical constituents and their potential health risks are mostly unknown to those who specify, install and use them. Investigations of materials that have indoor applications have documented emissions of a large variety of organic compounds, many of which are known or suspected carcinogens [11].

Formaldehyde is one example of a well-studied toxic chemical which is released from urea-formaldehyde resins. It is found in particle board, plywood and foam insulation as well as a number of adhesives. Low-level exposure under controlled experimental conditions produced significant eye, nose and throat irritant responses which increased with dose [18]. There are currently no set standards for the levels of exposure to volatile organic compounds (VOCs), such as formaldehyde, although a total emission of 1 $\mu g/m^3$ has been recommended as an interim guideline until more definitive health response data become available [19].

Vapors or gases can be absorbed or adsorbed on materials and released later when they can react with other airborne pollutants and be changed in character, most often with unknown results [2]. Indoor air chemistry is substantially different from outdoor air in that there is, for example, the presence of an increased surface-to-volume ratio as compared with the outdoor environment (enclosure materials to air volume), the presence of reactive indoor surfaces and the increased concentration of certain VOCs in the indoor air [10].

One of the ways to help ensure good IAQ through pollutant control is to use materials and energy systems with low emissions of substances that can cause minimal health or comfort problems [20]. Source control is the best strategy for reducing indoor air pollution. Careful selection of building materials can reduce the quantities of indoor-generated pollutants. This is a preventative strategy that involves the use of materials that emit no or low levels of pollutants, particularly VOCs. Natural materials such as wood and cotton are preferable to synthetics and metal is preferable to plastics [21]. Unfortunately, due to their low cost, synthetics have the current economic advantage [21]. The approach to controlling indoor air pollution at a source level is not new and has been proposed by others in the past [11, 15, 22]. There are also investigations into the effects on IAQ of the energy systems used for providing heating, cooling and ventilation to a building [23]. Source control strategy seeks to prevent IAQ problems before they begin by using the least offensive materials possible. Although IAQ is not the only factor involved in choosing the materials and energy systems for a building, the IAQ information can be considered if it is readily available. It then needs to be weighed against such factors as the cost of alternative materials or applications, aesthetic preferences, availability and so on. Source control does not provide complete relief from indoor air pollution, but eliminating at least the most offending substances or permanent internal sources from an architectural project will greatly reduce the overall IAQ problem.

Information Formatting

Information was gathered on the health risks, pollutants and alternatives and/or special techniques for using these materials and thermal energy systems to improve IAQ. It was necessary to select only that IAQ-related information which would be helpful to architects in choosing materials and energy systems in the design phase of a project. The main task was to extract the pertinent information from the information available on IAQ. The final step in the process was to sort the relevant information and reorganize it into an easy-to-use reference guide. The overall emphases were ease of use, pertinence of the information, understandability and flexibility. The information was compiled in three different ways to meet the needs of a variety of potential individual preferences in accessing information: one-page summaries, a written information matrix, and a hyper-text.

The One-Page Summary. These summaries include information in a concise written form to allow for quick referencing of the information on each specific indoor finish material or energy system on a two-sided single sheet of paper. A one-page summary (for carpets, for example) is divided into five sections: General Information, Alternatives and Techniques for Use, Pollutants, Health Risks, and References. On one side of the page, the 'what' information such as the General Information and Alternatives and Techniques for Use are provided. On the other side of the sheet, the 'why' information such as Pollutants, Health Risks, and References are provided.

The Data Matrix. This table provides an initial comparative overview of the information on each specific material or system, arranged in columns for each informational category: (a) Pollutants, (b) Health Risks, (c) Alternatives and (d) Techniques for Use. This allows for very quick, comparative reference of the information for those who prefer very concise, specific data.

The Hyper-Text. HyperCard software is used to create an IAQ HyperCard stack for building finishes and energy systems that can be browsed through on a Macintosh computer, which is widely used by architects. The 'cards' are set up to access the same information provided in the written guide with somewhat more ease of use for those with access to the HyperCard software. The information on the HyperCard stack is accessible by a variety of access points. The user beings with the 'home' card and supplemental choice cards which provide instructions on how to use the stack and allow the user to make access choices. The choices available are: specific indoor finish material, thermal energy system, or pollutants. The information on the health risks of specific pollutants and alternatives/techniques for use is gained by browsing the stack. Some schematic sample paths through the HyperCard stack are shown in figure 2.

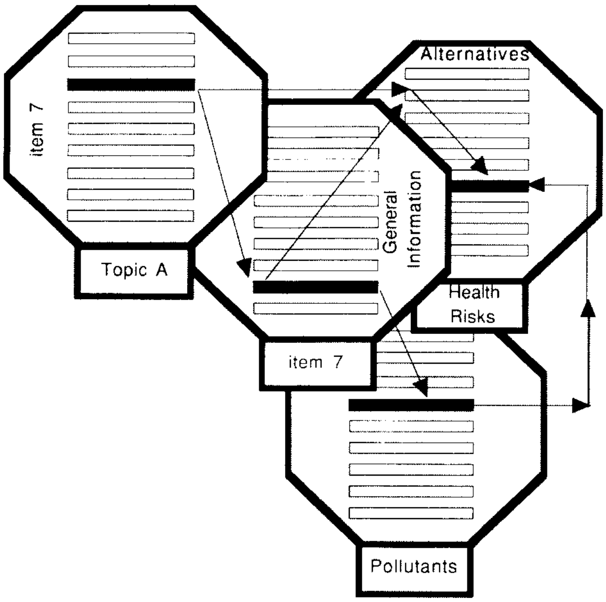

Fig. 2. Conceptual schematic for the IAQ guide HyperCard program showing direct sequential and indirect cross-referencing potential.

Conclusions and Recommendations

In this study, the compilation of design-related IAQ information on building finishes and energy systems from major research entities and publications has been accomplished. It has demonstrated a method of systematically obtaining and sorting the compiled information in order to create a practical reference for use by architects when selecting indoor finish materials and thermal energy systems. Also, it has provided a useful knowledge transfer link between the scattered IAQ research information related to envelope and energy system design and the practicing architectural community. The information provided in the guide so far makes it possible to tentatively evaluate major finish materials and energy systems based on their effect on the quality of the IAQ and consequently the health and comfort of the occupants. The proposed guide also serves to increase the level of consciousness and awareness of the issues involved in IAQ. It promotes a design-based approach directed specifically to the architectural community. It also promotes a building ecology approach to design, one which recognizes the interrelationships of all components of a building, the building occupants and the larger environment. The building ecology approach emphasizes the impact of indoor environmental factors on the building occupants' health and well-being. Building for health is becoming as much of a design priority as building for energy conservation has.

The guide can be used as a reference in an architectural office to obtain information on specific indoor finish materials and thermal energy systems. It can also serve as a working base from which to continue and encourage further research by the user. This guide utilizes the premise that minimizing indoor air pollution sources by selecting low- or non-polluting materials and energy systems can reduce the level of internally generated pollutants and thereby improve the quality of the indoor air. The guide provides the overview information needed to make choices regarding the overall compared impact of one indoor finish material or thermal energy system versus another. This information will allow for an assessment of these choices that previously may have gone unconsidered and consequently may have contributed to the IAQ problem through a lack of informed decision-making. Although the HyperCard program is an attached element, it is an integral part of this study. It is set up to guide the architect through the process of using it with minimal prior knowledge of HyperCard except the ability to open the software and use some of the basic functions to move through a HyperCard stack. It gives the user the opportunity at various places to add to the data cards if more information becomes available. This allows for an ongoing interactive process which will encourage the use and updating of the information due to the ease in doing so.

It would also be an asset to have a clearinghouse established for research information in which the process of this study could be consolidated and executed for a variety of disciplines simultaneously, funneling the appropriate information to those who can make direct use of it. Collecting this information for professional architectural use can be done by requesting Material Safety Data Sheets which provide information on the individual chemical constituents in the products. It is also recommended that the manufacturer's Quality Assurance System be requested. This study has shown one example of filling a part of the vast need for information in the area of improving indoor air quality through the selection of materials and thermal energy systems. In general, a synergistic approach of design, management, product modifications, maintenance and monitoring are all necessary to the technical control of indoor air pollution. An overall combination of good ventilation and low- or non-polluting building and finish materials and thermal energy systems will dramatically improve the quality of indoor environments.

Acknowledgments

The authors appreciate the support and the valuable comments of Professors J. Cook and D. Scheatzle during the development of this research.

References

1 Sammaljarvi E, Raunemaa T: Aerosol and Reactive Gas Effects by Electric Heating Units. Indoor Air '90: Proc 5th Intl Conf on Indoor Air Quality and Climate, Toronto, 1990, vol. 3, pp 653–658.
2 Turiel I: Indoor Air Quality and Human Health. Stanford, Stanford University Press, 1985, pp 93–106.
3 McNall PE: Indoor air quality status report. Proc Clima 2000, World Congress Organization on HVAC, 1985, p 13.
4 Testa C: Indoor Air Pollution: Remedies and Pitfalls. Indoor Air '90: Proc 5th Intl Conf on Indoor Air Quality and Climate, Toronto, 1990, vol 3, pp 325–327.
5 Engineering Interface Limited: Healthy Building Manual: Systems, Parameters, Problems and Solutions. Ottawa, Coordinating Council of Commercial, Institutional and Agricultural Energy Management Task Force, 1988, p 3.
6 CMHC: What CMHC Has Been Doing about Indoor Air Quality. Ottawa, Canada Mortgage and Housing Corporation, 1991.
7 Wann D: Biologic: Environmental Protection by Design. Boulder, Johnson Books, 1990, p 57.
8 DuPont P, Morill J: Residential Indoor Air Quality and Energy Efficiency. Washington, American Council for an Energy Efficient Economy, 1989, pp 21–47.
9 Levin H: Indoor air pollution: The environment moves indoors. ASTM Standardization News, Dec 1988, pp 34–38.
10 Ryan PB, Koutrakis P: Indoor air chemistry, an emerging field. Proc Indoor Air '90: 5th Int Conf on Indoor Air Quality and Climate, Toronto, 1990, vol 2, pp 489–493.
11 Hodgson AT, Girman GR, Newton AS, Winkes A: Emissions of Volatile Organic Compounds from Architectural Materials with Indoor Applications. Berkeley, Lawrence Berkeley Laboratory, Applied Science Division, 1983.
12 Fanger PO: Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy Buildings 1989;12:1–6.
13 Stockton MB, Spaite PS, MacLean JS, White JB, Jackson MD: Catalog of materials as potential sources of indoor air pollution. Proc IAQ '91: Healthy Buildings, Washington, 1991, p 280.
14 Tucker GW: Emissions of air pollutants from indoor materials: An emerging design consideration. Proc 5th Canadian Building and Construction Congr, Montreal, 1988, p 101.
15 Levin H, Teichman K: Technics: Indoor air quality for architects. Progressive Architecture, March 1991, pp 52–57.
16 ASHRAE: ANSI approves ASHRAE Standard 62-1989 on indoor air quality. Insights 1991; 6:1.
17 Crowther R: Indoor Air Risks and Remedies. Denver, Direction Publishers, 1989, pp 214–223.
18 Gupta KC, Ulsamer AG, Preuss PW: Formaldehyde in indoor air: Source and toxicity. Environ Int 1982;8:349–358.
19 Engstrom K: Building materials: A source of indoor air pollution. Indoor Air '90: Proc 5th Int Conf on Indoor Air Quality and Climate, Toronto, 1990, vol 3, p 679.
20 Tucker WG: Building with low-emitting materials and products: Where do we stand? Proc Indoor Air '90: 5th Int Conf on Indoor Air Quality and Climate, Toronto, 1990, vol 3, p 251.
21 Bower J: The healthy house; in Pearson D (ed): The Natural House Book: Creating a Healthy, Harmonious and Ecologically Sound Home Environment. New York, Simon & Schuster, 1989.
22 Molhave L: Indoor air pollution due to organic gases and vapours of solvents in building materials. Environ Int 1982;8:117–127.
23 Krafthefer BC, MacPhaul D: Ultrafine Particle Emission from Baseboard and Other Resistance-Type Heaters. Indoor Air '90: Proc 5th Int Conf on Indoor Air Quality and Climate, Toronto, 1990, vol 3, pp 659–664.