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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

IMPLEMENTING HEALTH-PROTECTIVE FEATURES AND PRACTICES IN BUILDINGS

WORKSHOP PROCEEDINGS

Federal Facilities Council Technical Report #148

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INTRODUCTION

It is estimated that Americans spend more than 85 percent of their time indoors, either at home, work, school or in health care, retail, recreational, or entertainment facilities. The quality of indoor environments—levels of indoor contaminants such as chemicals and bioaerosols, temperature and humidity, lighting, noise level, and furniture and equipment design—can influence a person's health,[1] comfort, and ability to perform his or her job, to learn, to heal.

Indoor environmental quality (IEQ), in turn, is influenced by building design, including the exterior envelope (walls, roof, windows, doors, materials); heating, ventilation, and air-conditioning (HVAC) systems; construction materials; and lighting design. IEQ is also influenced by building operations, maintenance, and housekeeping procedures. Although Le Corbusier once described a building as "a machine for living," a building is more like a living organism than an inanimate artifact. It is composed of integrated systems where actions in one area will have consequences that ripple through the entire building, affecting not only other building systems but also the-occupants in ways that are not fully predictable.

Increasing evidence, some scientific and much anecdotal, suggests that adverse health outcomes in employees, students, hospital patients, and others are linked to the presence of indoor pollutants and other aspects of poor-quality indoor environments. However, the certainty with which such attributions can be made varies. One confounding factor is that the effect on the population differs, with some groups or persons being more susceptible to contracting symptoms or diseases than others. In addition, some health-related impacts, such as lung cancer, occur only after long-term exposure to the causal agent.

Many buildings, even some of the best-designed ones, will develop problems that can affect the health of some occupants if operations, maintenance, or housekeeping practices are inadequate. Although the scientific evidence is not yet sufficient to document all of the suspected links between a variety of diseases and health problems to specific building features and practices, one point is clear: Building-related diseases and symptoms are *substantially preventable*. Prevention strategies include timely intervention to limit or eliminate exposure to causal agents, appropriate building design and construction, and good maintenance, operations, and cleaning practices.

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[1] The World Health Organization defines "health" as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.

POTENTIAL BENEFITS OF IMPLEMENTING HEALTH-PROTECTIVE FEATURES AND PRACTICES IN BUILDINGS

The magnitude of the investment in buildings is staggering. There are more than 107 million residential buildings and approximately 4.7 million additional nonagricultural and nonindustrial or "commercial" buildings in the United States today. On average, 2 million new homes and 200,000 commercial buildings are constructed each year. New health care facilities alone account for approximately $15 billion per year in capital expenditures, a figure that is projected to increase to $25 billion by 2010.

Given the magnitude of these numbers, researchers and others have projected that tens of billions of dollars could be saved annually from reduced absenteeism and improved employee performance if indoor environments were improved. Further, the National Occupational Research Agenda Indoor Environment Team has estimated that 6 million to 8 million respiratory infections, 1 million to 4 million episodes of asthma and allergies, up to 3,000 cases of Legionnaire's disease (associated with more than 70 deaths), and 2,000 to 11,000 deaths from heart disease or lung cancer could be prevented each year in nonindustrial indoor workers.

ABOUT THE WORKSHOP

The Federal Facilities Council (FFC)[2] and its parent organization, the Board on Infrastructure and the Constructed Environment (BICE) of the National Research Council (NRC), have a long-standing interest in the issue of indoor environmental quality. Prompted by increasing incidents of discomfort or illness in the nonindustrial workplace that could often be traced to indoor air quality issues, the BICE (then named the Building Research Board) issued the report "Policies and Procedures for Control of Indoor Air Quality" in 1987. In March 1996 the BICE convened a colloquium entitled "Building Performance and Worker Productivity: Issues in Research and Practice" to address how buildings could facilitate and enhance the performance of their occupants and how to do so in a quality indoor environment. A subsequent planning meeting was held in April 1998 to discuss the research questions that needed to be answered to quantify the relationships between the built environment and workplace productivity and establish a business case for implementing building features that enhance occupant wellness and productivity.

To continue the exploration of these complex issues and discuss ongoing research and possible strategies for implementing change in standards and practices for indoor environmental quality, the FFC convened a workshop, "Implementing Health-Protective Features and Practices in Buildings," in Washington, D.C., on November 17-18, 2003. (See Appendix A for the workshop agenda.) More than 50 researchers, scientists, architects, engineers, and economists from academia, government, and industry participated in the workshop. They provided a broad perspective on building performance and indoor environmental issues and their relationship to worker health and productivity. (See Appendix B for a list of participants.)

The workshop was designed to address four key questions:

1. What do we know about how building design and operations affect the health of indoor workers, hospital patients, students, and others?
2. Why do organizations fail to implement building features and practices that have been shown to improve indoor environmental quality?
3. What methods, strategies, and practices could be used to overcome barriers to implementing health-protective features and practices in buildings?
4. What practical actions can be taken by those in the building, health care, and other industries to create more healthful indoor environments?

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[2] The FFC is a cooperative association of U.S. federal agencies having interests and responsibilities related to all aspects of federal facilities design, construction, operations, and management. Established in 1953, the FFC operates under the National Research Council, the principal operating agency of The National Academies, a congressionally chartered, private, nonprofit corporation.

STATE OF KNOWLEDGE

Cause-and-effect relationships have been scientifically documented between waterborne pathogens in natural and man-made water systems and Legionnaire's disease and Pontiac fever in individuals; between microorganisms growing in contaminated ventilation and humidification systems and hypersensitivity pneumonitis and humidifier fever; between the release of carbon monoxide and carbon monoxide poisoning; between the presence of radon, environmental tobacco smoke (also called secondhand smoke), and asbestos in buildings and lung cancer. Poor or dim lighting in stairways and slight elevation changes in ramps can cause slips and falls that result in work-related injuries.

Persuasive evidence exists that links a variety of sources—endotoxins found in humidifiers; visible moisture and mold in ventilation systems; poorly maintained air-conditioning drainage pans; environmental tobacco smoke; and chemicals used in building materials, furnishings, and cleaning products—to the exacerbation of asthma and other respiratory symptoms in individuals. Available research studies also suggest that the presence of moisture or contamination in HVAC systems, low-level concentrations of formaldehyde, and materials that emit plasticizers (additives that keep them soft and pliable) into the air increase the *risk of developing* allergies, asthma, and some lower respiratory tract symptoms in some individuals. However, more study is required to better document and understand these relationships and establish safe exposure limits.

Building-related symptoms, sometimes referred to as "sick building syndrome," are nonspecific symptoms that are reported subjectively by occupants of a building and that often improve once the occupants leave. The symptoms include eye, nose, and throat irritations; headaches; fatigue; difficulty breathing; itching; and dry, irritated skin. Building-related symptoms are associated with a variety of factors, including low ventilation rates, high temperatures, volatile organic compounds emitted from building materials and carpets, fleecy materials used in furnishings, and inadequate cleaning practices.

PRACTICAL ACTIONS TO IMPROVE INDOOR ENVIRONMENTAL QUALITY

Based on this evidence and their own experience, the workshop participants identified a range of practical actions that could be implemented immediately by those in the building, health care, education, and other industries to create more healthful indoor environments, as follows:

Design and Construction

- Keep HVAC systems clean and dry—first by design and then by operation and maintenance.
- Provide adequate outdoor air ventilation and use natural ventilation where feasible.
- Commission newly constructed buildings and recommission existing ones to ensure they are built and operating as designed and specified.[3]
- Check the credentials of contractors installing HVAC and other equipment to insure they have the appropriate training.

Operation and Maintenance

- Develop an IEQ management plan and implementation procedures, and identify those accountable for implementation.
- Implement a proactive program to prevent indoor dampness and mold and remediate existing moisture problems.

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[3] Commissioning has been defined as a quality-focused process for verifying and documenting that a facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet an owner's project requirements. The scope of building commissioning includes integrated performance of the building envelope and architectural systems; site utilities; fire protection and suppression; special equipment; and mechanical and electrical controls.

- Eliminate indoor environmental tobacco smoke by prohibiting smoking inside a building or restrict smoking to physically isolated, depressurized smoking rooms that exhaust air to the outdoors.
- Monitor buildings to ensure they remain clean, dry, well ventilated, well lit, acoustically sound, and comfortable in terms of temperature and vibration.
- Maintain HVAC and other mechanical equipment, following installation and maintenance specifications, and proper cleaning, such as regularly changing filters and cleaning cooling coil drainage pans.
- Meet, at a minimum, ventilation rates in existing codes and maintain those over the life of a building.
- Control Legionella in building water systems.
- Keep indoor relative humidity below 70 percent.
- Maintain temperatures within the comfort range specified in thermal comfort standards.
- Limit, control, or eliminate indoor sources of volatile organic compounds, such as formaldehyde.
- Minimize pesticide use.
- Establish a reporting and feedback system for complaints related to IEQ. Reported complaints should be taken seriously, the concerns investigated, potential corrective actions identified, and the actions taken communicated back to the occupants involved.

BARRIERS TO KNOWLEDGE DISSEMINATION

Although there is a good deal of information available linking occupants' health and the quality of indoor environments, there is little evidence that building owners, designers, managers, occupants, or health care providers understand or routinely use this information to improve IEQ. Barriers to the dissemination of this information and its deployment in practice are many and varied. They include:

- Lack of leadership among building owners to champion or mandate health-protective features and practices within their properties;
- Fragmentation of the building industry and building processes and the resulting lack of accountability for IEQ;
- Lack of reporting and feedback systems for IEQ-related complaints;
- Lack of a "business case" to demonstrate a return on investment for implementing health-protective features and practices;
- Few building codes, standards, or regulations that are strictly health based;
- Lack of clarity regarding liability for building-related diseases or symptoms in occupants;
- A focus on the first costs (design and construction) of buildings as opposed to their life-cycle costs (planning, design, construction, operations, maintenance, renewal, disposal), health impacts, and impacts on productivity;
- Little or no formal training in health sciences among architects, engineers, facilities managers, and operators; and
- Competing, more urgent demands for limited resources.

SHORT- AND LONG-TERM STRATEGIES TO OVERCOME IDENTIFIED BARRIERS

Workshop participants identified a number of activities that could be implemented to overcome barriers to more widespread implementation of health-protective features and practices in buildings and provide lasting benefits for building occupants, owners, and the environment. Implementation of these activities will require sustained leadership for IEQ at all levels of management within organizations. Activities that could begin immediately include:

- Raising awareness of IEQ issues among the general public, building owners, and health care providers through public service announcements;
- Linking health-related processes and functions to existing programs or practices, such as energy savings performance contracts and energy audits;

- Establishing a "one-stop" information clearinghouse on the Web;
- Establishing incentive programs that motivate and recognize people for their contributions to improving IEQ;
- Establishing rating systems, similar to the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) or labeling programs similar to EnergyStar;
- Developing a "business case" for an IEQ program, including a measure of return on investment;
- Developing an evaluation matrix to demonstrate how one health-protective feature in a building might be traded off against other features and the resulting costs and benefits; and
- Identifying best-practice case studies and building on these success stories.

Longer-term activities include:

- Changing the way materials and products are specified and developing coherent guidelines for their application and installation;
- Partnering with the insurance and banking industries and building owners to demonstrate financial opportunities in building a certain way or adopting certain innovations;
- Working with regulatory organizations to develop guidance designed to protect the health of building occupants;
- Improving formal education and training programs for building professionals, operators, owners, maintenance staff, occupants, health care providers, and insurance providers; and
- Creating contract language for projects to include IEQ-supportive provisions.

RESOURCES

A large publicly accessible online bibliography on the topic of indoor environmental quality, health, and productivity is available at http://www.IHPCentral.org. This Web site contains approximately 1,100 papers from more than 100 major journals and conferences, organized by reference and study type and categories.

A recent paper, "The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity," contains a bibliography citing more than 600 rigorous studies on the relationship of hospital design to various clinical outcomes. (Available at http://www.healthdesign.org/research/reports/pdfs/role_physical _env.pdf.)

Additional resources for scientific and technical information related to health-protective features and practices in buildings are cited throughout this report. These resources include the following reports from the National Research Council:

Indoor Allergens: Assessing and Controlling Adverse Health Effects (1993). http://books.nap.edu/catalog/2056.html

Clearing the Air: Asthma and Indoor Air Exposures (2000). http://books.nap.edu/catalog/9610.html

To Err is Human: Building a Safer Health Care System (2000). http://books.nap.edu/catalog/9728.html

Damp Indoor Spaces and Health (2004). http://books.nap.edu/catalog/11011.html

Keeping Patients Safe: Transforming the Work Environment of Nurses (2004). http://books.nap.edu/catalog/10851.html

ORGANIZATION OF THIS REPORT

Chapter 1 summarizes the discussions and formal presentations that took place during the course of the workshop. The material presented reflects the views and opinions of the participants, not the deliberations of a formal NRC study committee. Nor were the participants asked to come to consensus or to make recommendations on the subject of indoor environmental quality and worker health. Nevertheless, the ideas expressed do provide guidance that building owners in both the public and the private sectors can implement immediately to improve indoor environmental quality. The summary also points to longer-term solutions that will require interactive dialogue within the broad community of stakeholders for better buildings and health care providers. Finally, there are research questions, yet unanswered, that should be addressed if the journey forward is to be focused and well disciplined.

Chapters 2 through 6 summarize the formal presentations given. Chapter 2 reviews the state of knowledge about indoor environments and occupants' health and cites findings from a number of scientific studies. Some parameters to measure the scope of the problem nationwide and potential financial and health-related benefits that could be achieved by investments in health-protective features and practices are discussed. Chapter 3 identifies research and empirical evidence to support health-related policies and practices in buildings as well as barriers to their implementation. Chapter 4 explores what is currently known about the effects of lighting on people's visual and circadian (daily biological rhythms) systems and the relationship of lighting to IEQ for some segments of the working population (young people, seniors, night-shift workers). Chapter 5 addresses how an improved physical environment can be used as a legitimate treatment modality in health care. The research agenda being developed by the Center for Health Design and the center's findings related to costs and benefits are the focus. Chapter 6 summarizes five case studies that analyzed the impacts on cost and time of changes to construction projects to incorporate specific health-related design elements—interior partitions, exterior enclosures, service systems, and structural elements. Proven approaches for incorporating desirable features across a wide range of buildings quickly and effectively are identified.

1

Workshop Summary

Buildings are designed, constructed, and operated for a variety of purposes. At the most basic level, buildings provide their occupants with physical protection from the weather and from natural and man-made hazards. At a higher level, they enable myriad activities: factories enable the production and distribution of goods; hospitals enable healing and recovery from illness and injury; schools enable learning at many levels; and workplaces enable productivity and the delivery of services to communities and countries. At the highest level, buildings symbolize and convey status, values, and power; memorialize people and events; and inspire people to specific behaviors, to create, and to formulate ideas.

Leading proponents in the building and health care industries envision a future in which buildings are designed, constructed, and operated from initial move-in to disposal to promote their occupants' health or wellness, security, comfort, and satisfaction; to enable their occupants to achieve organization missions and functional requirements; and to do these things cost effectively. A range of factors drive this vision:

- Greater awareness of health issues;
- Increasing costs of health care;
- An emphasis on physical security in response to terrorism as well as natural and man-made hazards;
- Growing recognition of the role of buildings as enabling environments for worker productivity, healing, and learning;
- Increasing concerns about energy conservation;
- The movement toward sustainability and sustainable building practices;
- Pressures to reduce the costs of owning, operating, and maintaining buildings;
- Lack of timely or adequate maintenance and repair of buildings;
- Increasing costs of litigation related to occupational safety and health; and
- Defective components and improperly installed equipment in buildings.

To fully achieve a vision of buildings that promote occupants' health and productivity, numerous issues must be resolved and barriers overcome. These include the lack of commonly accepted definitions or parameters for indoor environmental quality; limitations in the state of knowledge about links between building design, operations, and practices and occupants' health; and barriers to knowledge dissemination. Nevertheless, some aspects of the available knowledge are sufficient for building owners, occupants, and operators to immediately begin to improve indoor environmental quality by implementing a variety of relatively simple, practical actions. Over the long term, leadership on the part of building owners and operators and health-care professionals, training, educational initiatives, and additional research are required.

DEFINITIONS, STANDARDS, AND METRICS FOR INDOOR ENVIRONMENTAL QUALITY

Indoor environmental quality (IEQ) is an undefined term. To date, a definition and standards for IEQ that could be commonly accepted across the diverse group of building stakeholders—owners, operators, users, designers, engineers, researchers, health care professionals, educators, and the general public—have not been developed. Because these stakeholders have differing technical expertise, education, responsibilities, and values, lack of a common definition and standards hinders communication about and collaboration on IEQ issues and solutions.

Implicit in the development of guidance and standards is the development of performance indicators to measure how well the standards are being met. A fundamental issue is whether the quality of an indoor environment should be evaluated against a series of technical, building-related factors and standards—ventilation rates, for example—or against factors relating to the health of occupants, or some combination thereof.

Overall, there are no specific limits for exposures to measured volatile organic chemicals or microorganisms that serve as a breakpoint between acceptable and unacceptable indoor conditions. Identified risk factors, like dampness or the presence of certain exposure sources, are often used to indicate unmeasured causal exposures in indoor air. Because certain specific exposures are not measured, it is difficult to characterize indoor environmental quality in terms of whether exposures are acceptable.

Building-related factors that affect IEQ include the amounts and components of air pollution (indoors and outdoors); sources and rates of ventilation (i.e., outdoor air supply); temperature and humidity ranges; levels and sources of lighting; noise and vibration; building and furnishing materials; and operations and maintenance practices. Although IEQ is a result of the interrelationships of all of these factors, the systems used (heating, ventilation, etc.) and the management practices implemented are typically treated separately, rather than in an integrated or a holistic manner. Guidelines and standards for controlling these various aspects of IEQ are typically promulgated by nationally recognized technical and trade organizations. These include the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American National Standards Institute, ASTM International (formerly the American Society for Testing and Materials), and others. The guidelines are developed independently and in some cases may conflict.

Development of standards related to the health of building occupants poses a different set of issues. A fundamental issue is the state of knowledge about the links between building design, operations, and maintenance and occupants' health.

STATE OF KNOWLEDGE: WHAT DO WE KNOW ABOUT HOW BUILDING DESIGN AND OPERATIONS AFFECT THE HEALTH OF NONINDUSTRIAL INDOOR WORKERS, HOSPITAL PATIENTS, STUDENTS, AND OTHERS?

Cause-and-effect relationships have been scientifically documented between waterborne pathogens in natural and man-made water systems and Legionnaire's disease and Pontiac fever in individuals; between microorganisms growing in contaminated ventilation and humidification systems and buildings with water damage and hypersensitivity pneumonitis and humidifier fever; between the release of carbon monoxide and carbon monoxide poisoning; and between the presence of radon and environmental tobacco smoke (also called secondhand smoke) and lung cancer. Poor or dim lighting in stairways and slight elevation changes in ramps can cause slips and falls that result in work-related injuries.

Persuasive evidence exists that links a variety of sources—endotoxins found in humidifiers; visible moisture and mold in buildings or building ventilation systems; poorly maintained air-conditioning drainage pans; environmental tobacco smoke; and chemicals emitted from building materials, furnishings, and cleaning products—to the exacerbation of asthma and other respiratory symptoms in individuals.

Available research studies also suggest that the *risk of developing* allergies, asthma, and some lower respiratory tract symptoms is increased by the presence of moisture or contamination in heating, ventilation, and air-conditioning systems, low concentrations of formaldehyde, and materials that emit plasticizers (additives that keep them soft and pliable) into the air. However, more study is required to better document and understand these relationships and establish safe exposure limits.

Building-related symptoms, sometimes referred to as "sick building syndrome," are a set of nonspecific symptoms that are reported subjectively by occupants of a building and that often improve once the occupants leave. The symptoms include eye, nose, and throat irritations; headaches; fatigue; difficulty breathing; itching; and dry, irritated skin. Building-related symptoms are associated with a variety of factors, including low ventilation rates, high temperatures, organic compounds emitted from building materials, carpets and fleecy materials used in furnishings, and inadequate cleaning practices. Such symptoms are difficult to study because they do not indicate a specific disease.

BARRIERS TO KNOWLEDGE DISSEMINATION: WHY DO ORGANIZATIONS FAIL TO IMPLEMENT BUILDING FEATURES AND PRACTICES THAT HAVE BEEN SHOWN TO IMPROVE INDOOR ENVIRONMENTAL QUALITY?

Although building-related diseases and symptoms are substantially preventable, there are many reasons why the necessary intervening actions do not occur. These reasons, which are interrelated, can be generally categorized as awareness and motivation; financial considerations; accountability; and risk, liability, and lack of innovation.

Awareness and Motivation

The current state of knowledge about the links between occupants' health and indoor environments is a barrier in motivating owners and other stakeholders to implement health-protective features and practices in buildings. Much of the available research is reported in scientific and engineering journals and does not reach building owners, operators, managers, and users until it is more widely reported in the news media. For example, although some of the causes and potential effects of indoor mold and fungi on building occupants have long been discussed within scientific, research, and building engineering circles, the issue has only come to the attention of the general public with the widespread reporting of catastrophic situations and subsequent litigation.

Organizations, with some exceptions, have not implemented reporting and feedback systems to track problems occurring in their own facilities. Information about building-related problems and health complaints is not systematically gathered and analyzed, making it difficult to establish baselines for IEQ-related conditions or to identify recurring problems, patterns of problems, or trends. Without such information, efforts to recognize and address building-related health issues tend to be haphazard at best.

To date, providing for health-related features and practices in buildings is largely left to individual organizations and people who are willing to take a leadership role in championing them. Few standards, codes, or regulations are in effect that are strictly health based, although some life-safety codes and insurance underwriting requirements for fire protection and occupational safety do provide some health-related safeguards. In day-to-day operations, many organizations and people focus only on complying with existing regulations and standards and do not initiate voluntary practices, even if such practices would likely result in improved workplaces.

Financial Considerations

Information is also lacking to make a compelling "business case" for investment in health-protective features or to change existing practices. Building owners and others typically have limited resources to invest in buildings and many competing demands for those resources. Owners and organizations often choose to invest their resources where the benefits will be immediately visible, in response to an emergency or breakdown situation, or in a project or activity whose costs and benefits can be readily quantified into dollars.

The available evidence linking occupant health and IEQ is not easily quantifiable, nor are the results of implementing health-protective features and practices immediately visible. As a consequence, it is difficult for building operators, users, designers, and others to make a compelling business case to demonstrate the return on investment to be received from a particular health-related action. Similarly, it is difficult to compare and evaluate the costs and benefits of particular design features and conduct trade-off analyses.

When acquiring new buildings, the federal government and other organizations typically focus on the first costs (design and construction) and give less emphasis to the life-cycle costs (design, construction, operations, maintenance, repair, disposal). Implementing some health-protective design features in new buildings can lead to higher first costs, although the life-cycle costs may be lower. The financial value of future avoided illnesses or of improved work performance are seldom considered explicitly in decision making about building design or operations. Thus, the focus on first costs tends to devalue the benefits of long-term cost avoidance—investing more money today to prevent future problems and thus avoiding the costs of mitigation.

Accountability

In the construction and building management industries, the processes for design, construction, operations, and maintenance are typically discrete rather than integrated activities. Thus, for most facility projects, one group of stakeholders is responsible for programming and funding, another for design, still another for construction, and a fourth for maintenance, preservation, and operations. When these functions are separate, there are few incentives for those designing a facility to consider its life-cycle costs or to evaluate alternative materials, systems, or other components in terms of their impact on occupant health, long-term operations, and management. The groups responsible for design are rarely held accountable for the subsequent total operating costs of the facility. The group overseeing construction is responsible for and held accountable for completing the facility on time and on budget but not necessarily for ensuring that the facility will perform well, operate economically, and satisfy user requirements. In this type of operating environment, accountability for decisions and actions tends to be dispersed, so no one person or business unit can be held accountable for the results of particular actions, positive or negative.

Similarly, the stakeholders involved in the various processes—senior executives, chief financial officers, facilities managers and operators, architects, engineers, program and project managers, users, and occupants—tend to have different roles, responsibilities, technical expertise, and values. This hinders communication and collaboration across the stakeholder groups throughout the life cycle of a building. Furthermore, architects, interior designers, engineers, and facilities managers and operators receive little or no formal training or coursework in the health sciences and are not generally prepared to evaluate the consequences of their decisions about building materials, systems, and so forth on the health of a building's occupants.

Risk, Liability, and Lack of Innovation

All decisions and actions entail some level of risk: a measure of the probability and potential degree of positive or adverse effects. When acquiring a new building, owners, lenders, designers, engineers, and project managers all assume some level of financial or professional risk in bringing the project to fruition. Typically all will seek to mitigate or manage their risk through market analysis, by their choice of projects and means of achieving them, or by shifting the risk to others. They also purchase insurance against losses resulting from liability for injury to persons or the property of others.

In the area of building technology, liability issues are not clear, due, in part, to the dispersion of accountability. Owners, architects, and other stakeholders do not always know if they will be held liable for the performance of particular building systems and new technologies or innovative features or for any harm that may come to people or property as a result of their use. As a consequence, owners in particular seek to avoid the risk of liability by choosing to operate as they always have until litigation or directives from higher authorities force them to act in a different manner. In a similar vein, one reason that organizations have not systematically collected data on occupants' complaints about IEQ in their own buildings is concern that the organization might be held liable for actions taken or not taken on such complaints.

METHODS FOR IMPROVING KNOWLEDGE DISSEMINATION: WHAT METHODS, STRATEGIES, AND PRACTICES COULD BE USED TO OVERCOME BARRIERS TO IMPLEMENTING HEALTH-PROTECTIVE FEATURES AND PRACTICES IN BUILDINGS?

During the course of the workshop, the participants identified a number of activities that could be implemented to overcome the aforementioned barriers and to provide lasting benefits for building occupants, owners, and the environment. Implementation of all of the activities will require leadership from the top levels of organizations as well as champions at all levels of management. When top management commitment to an initiative is present, changes in organizational behavior and practice are much more likely to occur.

Awareness and Education Initiatives

Raising public and owner awareness of IEQ issues was identified as a critical first step toward gaining broad support and facilitating improvements in the building and health care industries. Organizations such as the American Institute of Architects, ASHRAE, and others can play a significant role in educating the general public. The Environmental Protection Agency (EPA) or other appropriate organizations could develop public service announcements that take a complicated issue such as IEQ and occupant health and package it in a way that informs and inspires people to act.

The federal government, which is the largest owner of built facilities in the United States and abroad, could play a significant role in outreach efforts and as the early adopter of change. This is not a new role for government. Recently, government agencies have taken the initiative to adopt sustainable building designs and practices, in some cases using the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) building rating system.

Another strategy for raising awareness of IEQ programs is to bundle them with successful existing programs. For example, energy savings performance contracts offer an opportunity to take advantage of ongoing building audits and financing potential by linking IEQ problems to an energy savings program and combining resources and functions.

An information clearinghouse could serve as a "one-stop" source of technologies and best practices related to IEQ and occupant health (see Chapter 7). The Whole Building Design Guide (www.wbdg.org) was cited at the workshop as an example of an information clearinghouse on buildings and their systems that could be expanded to handle IEQ issues.

Indoor quality programs and practices could also be promoted with incentive programs such as those used by the Federal Energy Management Program. This program motivates and recognizes people for activities they do on a day-to-day basis and for projects in which they implement practices that foster a healthier building environment and enhance occupant well-being and productivity.

In addition to raising awareness, workshop participants suggested that initiatives are also needed to motivate people to commit funds to health-related building programs and practices. Rating systems and labeling programs were both cited as nonregulatory means of stimulating awareness and changes in behavior and practices. They can also stimulate some competition and peer pressure—"If Joe down the street does it, I will"—which can drive adoption and use.

The LEED building certification program was discussed in some detail as a potential model for such an effort. LEED was thought to be simple enough to be easily understood by people with a wide range of backgrounds and responsibilities, while at the same time conferring some sort of status that has enough appeal to attract funding. Some participants suggested that health-related issues could potentially be incorporated into the LEED rating system although others disagreed.

A labeling program for buildings, similar to the Energy Star labeling program for appliances, was also suggested as a potential strategy to encourage building owners and others to invest in buildings and to incorporate health-protective features. Another model cited was the Center for Health Design's "Pebble Project" (see Chapter 5).

An opportunity exists for the National Research Council's Board on Infrastructure and the Constructed Environment to be the integrator, facilitator, sponsor, and dispenser of research that makes a convincing case for large holders of property, including the federal government, to create, design, operate, and manage a new generation of buildings that enhance health and well-being and support superior performance and efficiency. This could take several forms: brochures, guidelines, checklists, workshops, symposia, or an Internet-based clearinghouse.

Financially-Based Information and Metrics

There is a great need for measured data on the relationship of building design and operation practices to health and worker performance. Performance measurement is a central issue because it is difficult to manage and improve processes and practices that are not measured.

One of the metrics needed for an IEQ program is return on investment for building owners. Owners need to be able to justify in financial terms investments in the types of strategies being suggested for improving the performance of indoor environments. Some participants noted that EPA's Energy Star efficiency program is successful because it generates measurable phenomena and outcomes: If an organization changes its lighting or installs occupancy sensors, not only is there a change in the building environment, there is also a demonstrable change in the energy bill. This is a result that can convince an owner of the efficacy of a program and can lead to long-term change and acceptance.

A matrix could be developed to demonstrate how one feature in a new building might be traded off with another and the potential economic results. Such a matrix would help owners and others to recognize the values and consequences of trade-offs. Initial versions of such a matrix would not necessarily need to explicitly value individual items in terms of dollars, but could discuss qualitative values. However, explicit valuations for cost-benefit modeling are preferred.

Other metrics should reflect what people aspire to in buildings beyond thermal comfort, air quality, acoustics and lighting, and return on investment. It was noted that the United States spends billions of dollars on medical research. A return-on-investment analysis is not a driving factor in disease research because people implicitly know that it is the right thing to do. Implementing health-protective measures in buildings is also the right thing to do.

Communication, Monitoring, and Feedback

Communication is an important element in identifying problems, addressing them, and possibly avoiding more costly lawsuits, work-related illnesses and injuries, and declining productivity. The occupants of a building may be the most valuable monitoring "system" of indoor environmental quality, if there is a process and system in place for receiving input, responding to it, and tracking the response and results.

In its 2002 report, The Maryland State Task Force on Indoor Air Quality (IAQ) found that many if not most IAQ problems stem from a few basic causes: "(1) a failure to perform routine preventive maintenance on HVAC systems; (2) inappropriate balancing and reassessment of HVAC systems when buildings are renovated or modified; (3) inadequate housekeeping and maintenance of buildings particularly with respect to moisture control; and (4) failure to respond to employee IAQ complaints and communicate the findings and corrective actions back to the employees" (p.4). Regarding this last point, the Secretary of Maryland's Department of General Services noted that, in their experience, the best way to handle IAQ complaints is to "take them seriously, investigate the concerns, and communicate openly with the employees involved" (p. 15). The full report is available at http://www.dllr.state.md.us/labor/indoorairfinal/iaqfinalreportjuly12002.doc

Training and Guidelines

A common complaint about IEQ practices is the lack of adequate training and guidelines for many of those involved in the design, construction, use, and maintenance of a building. So there is a need for easy-to-use guidelines to correct problems in buildings and for widespread training of building professionals on how to best manage indoor environmental quality.

Federal agencies could use the best-value contracting process as opposed to lowest bid to get the best contractors to do the work. Contracts could emphasize the quality of training for personnel who install and commission the specified products. Furthermore, the contractor could also be required to provide appropriate training for the facilities people who will be operating the building systems.

Additional Actions

Additional suggestions for long-term strategies and activities to overcome existing barriers included:

- Changing the way materials and products are specified and developing coherent guidelines for their application and installation;
- Partnering with the insurance and banking industries and other large owner-investor organizations to demonstrate financial opportunities in building a certain way or adopting certain innovations;
- Looking for best-practice case studies and building on those success stories;
- Improving training programs for building professionals, operators, owners, maintenance staff, occupants, health care providers, and insurance providers; and
- Creating contract language for projects to include IEQ-friendly provisions.

PRACTICAL ACTIONS THAT COULD BE IMPLEMENTED BY THOSE IN THE BUILDING, HEALTH CARE, AND OTHER INDUSTRIES TO IMPROVE INDOOR ENVIRONMENTAL QUALITY

Many buildings, even the best-designed ones, will develop problems that can affect the health of some occupants if operations and maintenance practices are inadequate. During the course of the workshop, participants identified a wide range of actions that could be implemented immediately by those in the building, health care, and other industries to create more healthful indoor environments:

- Monitor buildings to ensure they remain clean, dry, well ventilated, well lit, acoustically sound, and comfortable in terms of temperature and vibration.
- Develop a checklist of items that should be monitored regularly to aid operations and maintenance staff.
- Eliminate indoor environmental tobacco smoke by prohibiting smoking inside a building or restricting smokers to physically isolated, depressurized smoking rooms that exhaust air to the outdoors.
- Implement a proactive program to prevent indoor dampness and mold and remediate existing moisture problems.
- Keep heating, ventilation, and air-conditioning (HVAC) systems clean and dry—first by design and then by operation and maintenance.
- Maintain HVAC and other mechanical equipment, following installation and maintenance specifications, and proper cleaning, such as regularly changing filters and cleaning cooling coil drainage pans.
- Provide adequate outdoor air ventilation and use natural ventilation where feasible.
- Meet, at a minimum, ventilation rates in existing codes and maintain those over the life of a building.
- Control Legionella in building water systems (guidelines available from ASHRAE and others).
- Keep indoor relative humidity below 70 percent.
- Maintain temperatures within the range specified in thermal comfort standards.
- Limit, control, or eliminate indoor sources of volatile organic compounds, such as formaldehyde.
- Develop an IEQ management plan and assign a person to implement it.
- Minimize pesticide use.
- Check the credentials of contractors installing HVAC and other equipment.
- Establish a reporting, correction, and feedback system that encourages building occupants and others to identify problems early. If or when the problems are corrected that information should be communicated back to

the occupants. Once a decision has been made about whether the problem can or will be corrected, the activities and timeframe for correcting it should also be communicated back to the occupants.

- Commission new buildings and recommission existing ones.

Building Commissioning and Recommissioning

Many workshop participants suggested that if building owners and operators routinely commissioned new buildings and recommissioned existing ones, many IEQ issues could be prevented or mitigated. This suggestion is based on logical expectations but has not been scientifically documented. Building commissioning is a process that encourages and measures quality. Draft ASHRAE Guideline 0-200X describes the commissioning process as:

> . . . a quality-focused process for enhancing the delivery of a project. The process focuses on verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements.

The scope of building commissioning includes integrated performance of the building envelope and architectural systems; site utilities; fire protection and suppression; special equipment; mechanical (HVAC, plumbing, piping); electrical (power, lighting, low voltage); and controls. The process, however, goes beyond mechanical systems, promoting a cradle-to-grave approach for optimal long-term building performance. The National Institute of Building Sciences (www.nibs.org), the Building Commissioning Association (www.bxca.org), and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (www.ashrae.org), among other organizations, have developed guidelines related to building commissioning and recommissioning.

2

Indoor Environments and Occupants' Health: What Do We Know?

Mark J. Mendell

Why are indoor environments important to people's health? People in the United States spend about 85 percent of their time indoors. Also, indoor exposures to pollutants are different from outdoor exposures, often at higher concentrations. Furthermore, a given amount of pollutant released indoors is a thousand times more effective at causing human exposure than when released outdoors. A growing body of scientific evidence now suggests that indoor environments are associated with a variety of adverse health effects and related economic impacts.

A number of factors affect indoor environmental quality (IEQ), including a building's design, construction, operation (including ventilation and thermal control), and maintenance (including the ventilation system and the building structure, housekeeping, and preventing leaks), the furnishings and contents, and its use—whether it is an office building, hospital, laboratory, etc. Occupants' activities are also important. Pollutants can come from outdoor air or soil and substantially influence what is happening indoors.

WHAT DO WE KNOW ABOUT THE RELATIONSHIP OF IEQ TO THE HEALTH OF BUILDING OCCUPANTS? HOW CERTAIN ARE WE OF THESE RELATIONSHIPS, THAT IS, WHAT IS THE SOURCE OF THIS KNOWLEDGE?

In scientific research the highest degree of certainty is provided through documented causal relationships. For example, with an infectious disease, you can document the cause-and-effect relationship between the organism, the environment, and the people exposed and infected.

Documentation of causal relationships requires a large body of scientific research, significant findings replicated in different settings and populations, findings that are consistent across studies, and studies that are biologically plausible and free of substantial error from bias and confounding. It is also helpful to demonstrate that, when the suspected causal exposure is greater, the risk of the disease is greater as well. It is often difficult to convincingly document many relationships that we believe may be causal. We have different levels of certainty about whether many of the specific aspects of IEQ cause health problems for occupants.

In terms of IEQ and occupants' health, causal relationships have been documented as shown in Table 2.1.

Research has clearly documented that the bacterium *Legionella pneumophila* can grow in water systems in buildings and cause a number of diseases in occupants, including Legionaire's disease, which has a high rate of fatality, and Pontiac fever, which causes a mild fever in most people who are exposed.

TABLE 2.1 Documented Causal Relationships Between IEQ and Occupants' Health

Causal Agent	Resulting Health Effect
Legionella pneumophila (bacterium)	Legionnaire's disease Pontiac fever
Microorganisms (unidentified)	Hypersensitivity pneumonitis/humidifier fever
Carbon monoxide	Carbon monoxide poisoning
Lead	Lead poisoning, neurological damage
Environmental tobacco smoke/radon/asbestos	Lung cancer

Two distinct diseases—hypersensitivity pneumonitis and humidifier fever—are caused by microorganisms growing in contaminated ventilation systems, contaminated humidification systems, and buildings with water damage from leaks. Causation of these serious diseases from exposures in buildings has been repeatedly documented, although in many cases the specific microorganisms causing the diseases have not been identified.

Carbon monoxide causes serious health effects, including death. In commercial buildings it generally results from entry of vehicle exhaust into indoor air by way of connected parking garages. In homes, carbon monoxide exposures often result from poorly vented combustion appliances.

Lead is present in old paint in older buildings such as homes and schools. Lead poisoning, which can result in serious neurological effects, sometimes occurs when infants and children eat the dust and particles from peeling paint. Lead poisoning is not known to be a significant problem in commercial buildings.

Substantial evidence exists that radon and asbestos occurring at high levels in occupational settings cause lung cancer. There is also clear evidence from studies, mostly of people living with active smokers, that environmental tobacco smoke causes lung cancer. An individual is not likely to observe the relationships between tobacco smoke, radon, asbestos, and lung cancer because it may take 20 to 30 years for the disease to manifest.

Although the causal relationships are not fully documented, there is persuasive scientific evidence linking a number of other indoor environmental factors to occupant health (see Table 2.2). A body of research with replicated significant findings exists, but the evidence is not sufficient to convince everyone that a causal relationship exists between a certain exposure and specific health effects.

Many studies have shown that low ventilation rates in buildings are associated with an increase in building-related symptoms among occupants. The term "building-related symptoms," what others might call "sick building syndrome," is defined as a set of nonspecific symptoms reported subjectively by occupants of a building that often improve when they leave the building. Symptoms include eye, nose, and throat irritations; headaches; fatigue; difficulty breathing; itching; and dry, irritated skin. It is difficult to study these symptoms because they do not indicate a specific identifiable disease. There are probably a number of exposures and biological response processes occurring simultaneously in the causation of these symptoms. In addition, these symptoms are known to be

TABLE 2.2 Persuasive Scientific Evidence Linking IEQ and Occupants' Health

Agent/Factor	Observed Health Effects
Low ventilation rate (no threshold?)	Building-related symptoms
Visible moisture and mold	Asthma and respiratory symptoms
Air-conditioning or humidification systems (presence of)	Building-related symptoms
High temperatures (even within comfort envelope)	Building-related symptoms Reduced performance Poorer perceived air quality

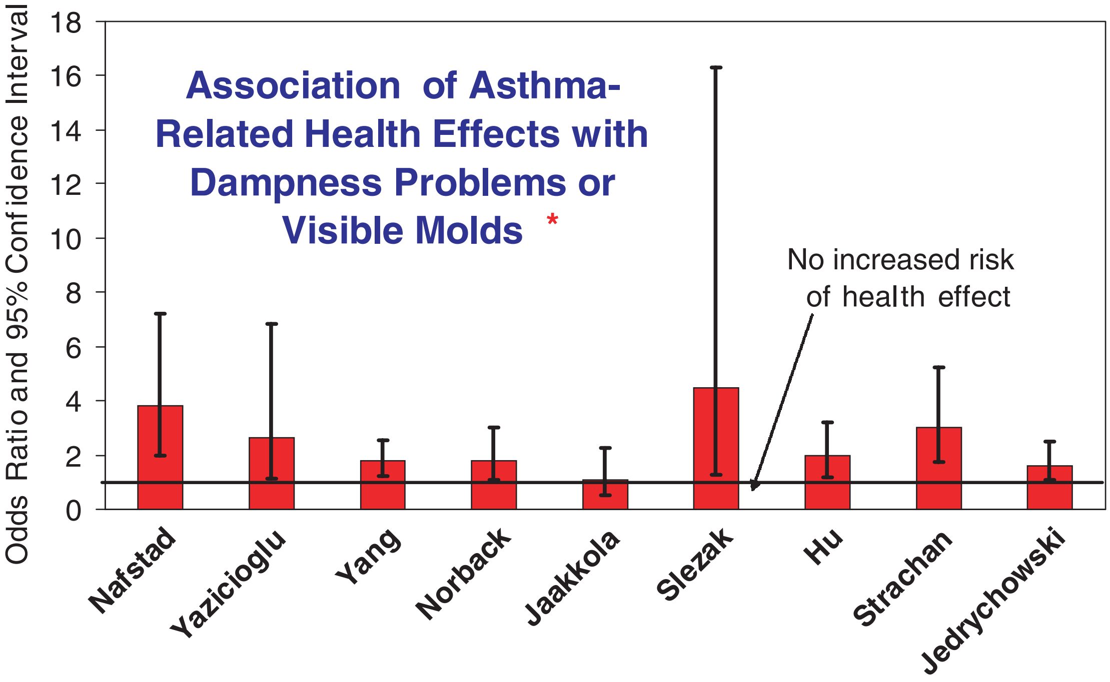

FIGURE 2.1 Association of asthma-related health effects with dampness problems or visible molds.
SOURCE: Institute of Medicine. 2000. *Clearing the Air: Asthma and Indoor Air Exposures.* Washington, D.C.: National Academy Press.

influenced by psychological factors. The challenge to identifying specific causal indoor exposures is to disentangle the biological processes that together present this confusing set of symptoms.

Clear evidence exists that visible moisture and mold in buildings are related to an increase in asthma and respiratory symptoms among occupants, although it is still not known what it is about the moisture that actually causes the adverse health effects. Current measurements of molds have not yet implicated specific molds as the key problem resulting from moist conditions.

The Institute of Medicine has reviewed the available science on building moisture's effects on occupants' health. Figure 2.1 identifies nine studies that consistently found some increase in risk associated with dampness. For almost all of them the confidence interval exceeds one, meaning that it is a statistically significant increase. But it is not known, in a way that can be measured and regulated, what the dampness represents in terms of specific exposures causing the illness.

Air-conditioning and humidification systems have been shown to be associated with an increase in building-related symptoms compared to buildings without such systems. Again, the causal exposures for this health effect are not known. The presence of these ventilation systems may pose a risk that, if the systems are poorly designed and maintained, they may become contaminated, thereby increasing the occurrence of building-related symptoms among occupants.

Also, high temperatures—particularly above the currently accepted comfort envelope (approximately 23 to 26 degrees Celsius, or 73 to 79 degrees Fahrenheit, in summer) and even at the higher end within the comfort envelope are associated with an increase in building-related symptoms, a reduction in occupants' performance, and a perception of poor air quality.

There are a number of other items for which only suggestive scientific evidence for a cause-effect relationship is available. For these there are relatively few studies, studies with conflicting findings, or studies with some

TABLE 2.3 Suggestive Scientific Evidence Linking IEQ and Occupants' Health

Agent/Factor	Observed Effects
Low ventilation rate	Increased transmission of respiratory disease (flu, colds) Decreased performance
HVAC moisture/contamination	Lower respiratory tract symptoms
Bacterial endotoxin	Building-related symptoms
Airborne fungi	Building-related symptoms
Formaldehyde at low concentrations	Development of allergies
Volatile organic chemicals	Irritation symptoms
Carpet and fleecy materials	Building-related symptoms
Very low humidity	Dryness symptoms
Soft plastic materials	Development of allergies/asthma
Recent renovation	Development of allergies
Poor space cleaning	Building-related symptoms
Increased view (or daylighting)	Increased performance

errors. It is important to remember that just because a number of studies show that two things are correlated statistically, it does not necessarily mean that one causes the other (see Table 2.3).

In a number of studies, low ventilation rates have been associated with increased transmission of a variety of infectious respiratory diseases such as flu and colds and decreased occupant performance. The presence of moisture or contamination in heating, ventilation, and air-conditioning (HVAC) systems has been associated with an increase in respiratory symptoms. This can be seen in data collected by the National Institute for Occupational Safety and Health (NIOSH) from a large number of buildings that were investigated for health complaints (see Figure 2.2).

The NIOSH study found that when a building has poor drainage in the pans underneath the air-conditioning cooling coils, there is a 160 percent increase in the risk of multiple work-related respiratory symptoms. These symptoms include wheezing, shortness of breath, tight chest, and cough. If there is debris in the air intake of the building, there is a 100 percent increase in risk for these multiple building-related respiratory symptoms. Although these are simply symptoms, they may indicate serious respiratory disease or sensitization, such as asthma.

Bacterial endotoxin, a substance often found in the environment, comes from bacteria that like moist locations. Several studies have found bacterial endotoxin to be related to an increase in building-related symptoms among occupants. Airborne fungi also have been measured and in some recent studies found to be related to an increase in symptoms, although in many studies they have not been related to symptoms.

Formaldehyde at surprisingly low concentrations has been found to be related to risk of development of asthma and allergies. Volatile organic chemicals are another exposure producing inconsistent findings in many studies. A growing number of recent studies have revealed that overall volatile organic chemicals and specific organic chemicals in indoor air have been related to irritation symptoms.

The presence of carpet and fleecy materials such as cloth-covered partitions or walls has been found to be related to an increase in building-related symptoms. Extremely low humidity has been associated with dry, irritated skin. But it is important to note that this does not mean that buildings should be humidified, because the risks associated with humidifiers, and potentially with high humidity, are much greater than those for low humidity.

Soft plastic materials (such as vinyl wallpaper) or objects with plasticizers (the chemical additives that keep plastics soft and pliable) that emit the plasticizers into the air are associated with the development of allergies and asthma in children. This is a new area of research and is potentially very important.

In addition, recent renovation of a building has been shown to be related to the development of allergies in infants because the new paint, flooring, and other materials emit volatile organic chemicals into the indoor air.

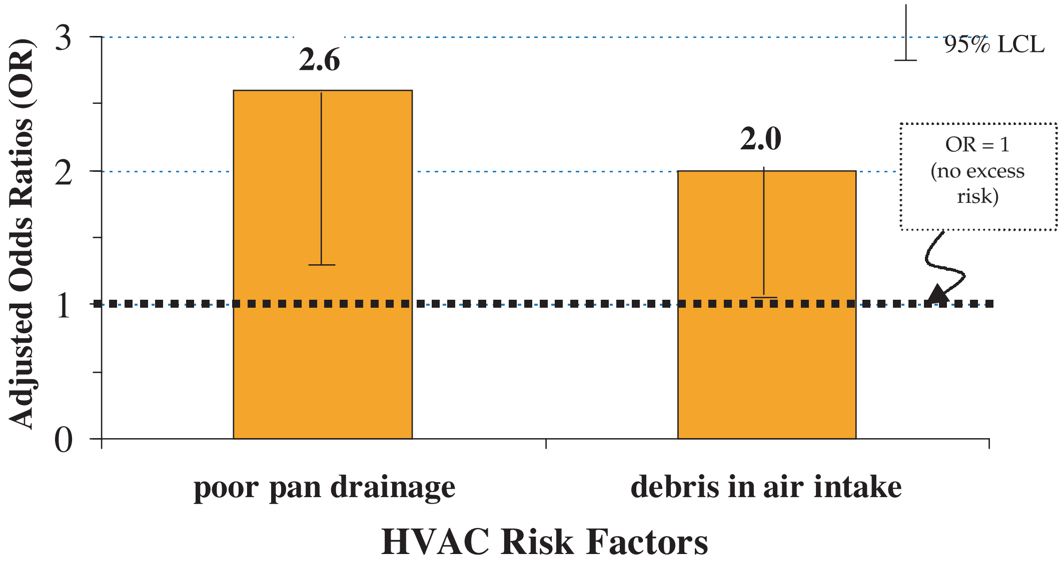

FIGURE 2.2 Risk factors for multiple work-related respiratory symptoms.
SOURCE: 1993 NIOSH Office Investigations**
** Mendell et al., American Journal of Industrial Medicine 2003

Poor space cleaning in office buildings has also been shown in some studies, but not all, to be related to increases in occupants' symptoms. In terms of positive influences, a few studies have shown that increased views out windows or possibly day lighting are related to increased occupant performance, but it is not yet clear how to interpret these results.

Overall, there are no specific limits for exposures to measured volatile organic chemicals or microorganisms that have been shown to serve as a breakpoint between acceptable and unacceptable indoor conditions. Therefore, identified risk factors, like dampness or the presence of certain exposure sources, are often used to indicate unmeasured causal exposures in indoor air. Because we lack certain specific exposures known to be important to measure, it is difficult to characterize indoor environmental quality in buildings in terms of whether exposures are acceptable. That, unfortunately, is the state of the science with respect to many aspects of IEQ and occupants' health.

Still, we can look to some of the risk factors that are known to be important and determine what we need to do to improve indoor environments for the people living and working in them. The research indicates that we should:

- Eliminate indoor environmental tobacco smoke,
- Prevent indoor dampness and mold,
- Provide adequate outdoor air ventilation,
- Control *Legionella* in building water systems (guidelines available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers and others),
- Keep HVAC systems clean and dry—first by the initial design and then by operations and maintenance,
- Use natural ventilation where feasible,
- Improve temperature control and avoid higher temperatures, and
- Limit/control indoor sources of volatile organic chemicals.

So how much of a problem do we have? Some of the best data available on the state of commercial buildings in the United States are from the Environmental Protection Agency's (EPA) Building Assessment and Survey

Evaluation Study, which included 100 representative office buildings during the 1990s and collected information on various factors and exposures.

Scientific research has shown, as mentioned above, that occupants in buildings with water damage or poorly maintained drain pans are clearly at risk for developing respiratory illnesses. EPA's statistics show that:

- 40 percent of the buildings had no scheduled cleaning of the drain pans,
- 30 percent had very dirty drain pans,
- 34 percent had current water damage in occupied spaces,
- 71 percent had past water damage in occupied spaces,
- 15 percent had current water damage from leaking roofs, and
- 50 percent had past water damage from the roofs.

Overall, 43 percent of the buildings had some current water damage and 85 percent had past water damage. These are sobering numbers for estimating the potential magnitude of existing problems related to IEQ and human health.

The National Occupational Research Agenda Indoor Environment Team made some estimates based on available data of the potential magnitude of benefits that might result from improved indoor work environments, such as offices. The estimates excluded costs of deaths and focused only on the costs of health care and lost productivity at work. It estimated that 6 million to 8 million respiratory infections could be prevented each year, at an annual savings of $3 billion to $5 billion. One million to 4 million episodes of asthma and allergies could be prevented, at a savings of $200 million to $600 million a year. And building-related symptoms could be prevented in 8 million to 30 million people, resulting in a productivity benefit of $4 billion to $70 billion annually.

Furthermore, as many as 3,000 cases of Legionnaire's disease (associated with more than 70 deaths) could be prevented annually, for a savings of at least $30 million. If we could eliminate environmental tobacco smoke from workplaces, 2,000 to 11,000 deaths could be prevented each year from heart disease and lung cancer, for a savings of $30 million to $140 million. This figure does not include the possible additional benefits to students in schools, patients in hospitals, or visitors to public buildings.

There are multiple forces likely to change building design, operation, and maintenance practices that will, in turn, improve IEQ in buildings, including an increasing recognition of the health and productivity benefits of good indoor environmental quality; increasing costs of health care; increasing demand for excellent health and healthy environments; and, across multiple sectors, greater recognition of accountability for providing healthy indoor environments. Hopefully, as the demand for improved IEQ builds, we will have increased ability and knowledge to take appropriate actions.

In summary, there is a clear need to better implement what is known about good indoor environmental quality to improve the health and performance of building occupants. Improved IEQ starts with appropriate design and construction of buildings and continues with good operations and maintenance practices throughout the life of each building.

ABOUT THE PRESENTER

Mark J. Mendell, Ph.D., is an environmental epidemiologist, with the Lawrence Berkeley National Laboratory's Indoor Environment Division. Dr. Mendell has conducted research on health effects of indoor environments for many years and has been published extensively. He was formerly at the National Institute for Occupational Safety and Health, where for six years he led the National Occupational Research Agenda Indoor Environment Team. His research interests include the effects of indoor chemical and microbiologic pollutants in offices, schools, and homes on asthma, infectious disease, and building-related symptoms, with specific interests in risks related to ventilation systems, indoor chemical emissions, and indoor moisture.

3

Health-Protective Features and Practices in Buildings

James E. Woods

INTRODUCTION AND PROBLEM STATEMENT

My objectives are to identify (a) the best-available research and empirical evidence that supports facilities-related policies and practices that could result in better indoor environmental quality (IEQ) if implemented and (b) barriers to the implementation of these policies and practices. To achieve these objectives, several topics and issues are addressed. These include the purposes of buildings, current building stock, current drivers for building performance, and stakeholders. A second topic is the current state of knowledge about the performance of buildings and their systems as they relate to environmental controls and health-protective practices. A final topic is barriers to improving performance of new and existing facilities.

Primary and Secondary Purposes of Buildings

Historically, buildings have been designed, constructed, and operated for two fundamental purposes: (1) to provide for the health, safety, and security of their inhabitants and (2) to facilitate the well-being and productivity of occupants, building owners, and managers. These purposes follow two basic principles: the Maslow Hierarchy of Needs[1][1] and the definition of "health" in the Constitution of the World Health Organization [2].[2]

The five functional categories of buildings addressed are: residential, educational, health care, office and mercantile, public assembly and worship. The industrial building category is not discussed because exposures of workers to indoor environmental stressors[3] in industrial facilities are typically considered to be significantly different than exposures of occupants to indoor environmental stressors in nonindustrial facilities.

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[1] The five levels in Maslow's Hierarchy of Needs are: (1) Physiological, (2) Safety and Security, (3) Belonging, (4) Esteem, and (5) Self-actualization.

[2] The World Health Organization definition: "*Health* is a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity."

[3] In this paper, IEQ is defined as the nature of physical and chemical characteristics (i.e., stressors) within the building that stimulate physiological receptors and result in human (i.e., physiological, psychological, pathological) responses. And *exposure* (E) is defined as: E = IIC dT dS, where C is type and concentration (i.e., intensity) of the stressor(s), S is the space in which exposure occurs, and T is the time in each space during which the stressor(s) stimulate the receptors.

Building Stock

Approximately 4.7 million nonresidential, nonagricultural, nonindustrial buildings and 107 million residential buildings exist in the United States [21, 22].[4] The annual rates of growth and replacement of this building stock have been approximately 2 percent for residential buildings and 4 percent for nonresidential, nonindustrial buildings for the past 20 years [23]. Thus, approximately 2 million residences and 200,000 “commercial” buildings are constructed annually in this country. A summary of characteristics for four types of “commercial” and four types of residential buildings is shown in Table 3.1.

The four functional categories of “commercial” buildings were selected because they represent a significant percentage of the existing building stock (i.e., note that with the warehouse and “vacant” categories from the total population, these four categories represent more than 50 percent of the total). Several important demographic factors may be observed from the table:

- The percentages of government-owned office buildings and health care facilities are relatively low, while the percentage of government-owned (i.e., local, state, and federal) educational facilities is relatively high, and the percentage of owner-occupied facilities appears to be approximately inversely related to the percentage of government-owned facilities.
- The distribution of the building stock (i.e., both commercial and residential) appears to follow a geographic pattern in which the largest numbers of buildings in each category are located in the southern (i.e., Southeast and Southwest) part of the United States, followed by the Midwest, West, and Northeast.
- The median sizes of the commercial buildings are significantly smaller than are typically perceived. Half of the commercial buildings are in the smallest category (1,001 to 5,000 ft^2), and three-quarters are in the two smallest sizes (1,001 to 10,000 ft^2). Approximately 5 percent were larger than 50,000 ft^2, and less that 2 percent were larger than 100,000 ft^2. However, the population distribution appears to be inversely proportional to these numbers: nearly half of all workers are in 5 percent of the buildings (i.e., larger than 50,000 ft^2), while only about one-quarter of all workers are in 75 percent of the buildings (i.e., 10,000 ft^2 or less).
- The median age of buildings in all categories is more than 20 years, and the residential stock appears to be older than the commercial stock. The median ages exceed the life expectancy for much of the equipment in these buildings.

Concept of Continuous Degradation

The concept of continuous degradation of the building stock was proposed in 1988 [24] and continues to serve as a model with which the chronology of building performance can be characterized. Briefly, this concept states that buildings are not conceived to cause harm, but as they progress from the planning and design stages through construction to operations, degradation will occur through compromises unless it is detected and intervention is implemented. Based on studies conducted in the 1980s, this concept proposed that 20 to 30 percent of the building stock in North America and Western Europe was sufficiently dysfunctional to manifest in occupants symptoms of disease and that another 10 to 20 percent existed in a classification called “undetected problems,” leaving a residual population of 50 to 70 percent as “potentially healthy” buildings. Since then several studies have been reported that support this concept, three of which are mentioned here:

- During the 1990s, the U.S. General Accounting Office (GAO) published a series of reports on the conditions of American schools [25]. The GAO reported that about 58 percent of school facilities in the United States

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[4] Note the Energy Information Agency (EIA) [17] defines the nonindustrial, nonagricultural, nonresidential category of buildings as “commercial” buildings. This category contains several functional categories, including office, mercantile, warehouse and storage, retail service, food service, education, religious worship, public assembly, “vacant,” food sales, lodging, malls, health care, and public order and safety.

TABLE 3.1 Summary Characteristics of Four "Commercial" Building Types and Four Residential Building Types from EIA [21, 22]

Building Category	Description	% Total Buildings[a]	% Government Owned	% Owner Occupied	% Census Distribution				Median Size (ft^2)	Median Age (years)
					NE	MW	S	W		
Office	General office space, professional office, administrative office	15 (26)	7	69	14	23	42	20	4,500	24.5
Education	Preschool, K-12, classroom buildings in universities and colleges	7 (11)	59	33	9	13	37	41	8,000	35.5
Health care	Diagnostic and treatment facilities:	3 (4)	6	60	11	26	46	16		
	• Inpatient								65,000	29.5
	• Outpatient								4,500	9.5
Public Assembly	Social and recreational activities	6 (11)	21	67	14	29	41	16	6,500	32.5
Residential			NA[b]		19	23	36	22	NA[b]	
	• Single Family (SF)	59		88						40
	Detached Garage									35
	• SF Att Gar.	10		71						50
	• Multi-Family (MF)	9		22						40
	(2-4 units)									30
	• MF (≥5)	16		10						
	• Mobile Home	6		84						

[a] Numbers shown in parentheses represent percentages of total buildings when "warehouses" and "vacant" categories have been removed from the total population (i.e., revised total population is 3.8 million rather than 4.7 million buildings).

[b] Data on government-owned residential facilities were not provided in [22].

had at least one unsatisfactory environmental condition, and about 13 percent had five or more. Those most frequently reported were acoustics for noise control (28 percent), ventilation (27 percent), physical security (24 percent), heating (19 percent), indoor air quality (19 percent), and lighting (16 percent). The GAO estimated that schools nationwide needed to spend about $112 billion to repair or upgrade them to good overall condition, an average of $1.7 million per school.

- In 2000 the Institute of Medicine [26] reported on its findings regarding the relationship of asthma and indoor air quality. One of its conclusions was that "damp conditions [in residential and commercial buildings] are associated with the presence of symptoms considered to reflect asthma; symptom prevalence among asthmatics is also related to dampness indicators." The underlying causes of the moisture problems were reported to include "inadequate financial resources to repair leaks, that the relevant features of building design, operation and maintenance may be determined substantially by speculative builders or other decision-makers who are substantially unaffected by future moisture problems. Similarly, landlords who do not reside in the affected building may not be motivated to repair water leaks rapidly."
- In January 2003 the GAO released a report declaring that federal real property was a governmentwide "high-risk" area [3]. The GAO reported that the Department of Defense found that as many as two-thirds of its 621,850 installations and facilities "are not adequate to meet the war-fighting and operational concepts of the 21st century." The GAO also reported that, when compared to other schools nationally, "schools operated by the Bureau of Indian Affairs (BIA) were generally in worse condition, had more environmental problems, lacked certain key facilities, and were less able to support advancing technologies." BIA reported in 2001 "a significant backlog of deferred maintenance and that the conditions in the educational facilities were negatively affecting the ability of the children to perform." The General Services Administration (GSA) reported to the GAO that "half of its 1700 buildings needed repairs at about $5.7 billion." In 2001, the GAO observed poor health and safety conditions in GSA buildings due to "dysfunctional air ventilation systems, inadequate fire safety systems, and unsafe water supply systems."

The population at risk in these degrading buildings is large. For the commercial buildings shown in Table 3.1, the ratios of total occupants to employees range from approximately 1:1 for offices, to 4:1 in educational facilities, to 7:1 for health care facilities, to more than 50:1 in some public assembly buildings. Based on the findings that the population spends approximately 90 percent of its time indoors, the concept of continuous degradation was used to project initial estimates of the probabilities of exposures in "healthy" and "sick" residences and commercial buildings [27]. These estimates ranged from 9 to 25 percent probabilities (i.e., 15 million to 60 million U.S. occupants) who may be exposed in both "sick" residences and "sick" commercial buildings, to 25 to 50 percent (i.e., 40 million to 120 million occupants) who may be exposed in both "healthy" residences and "healthy" commercial buildings, to 30 to 70 percent (i.e., 40 million to 170 million occupants) who may be exposed in either "sick" residences or commercial buildings. These numbers are substantially higher than the 82 million to 89 million employees estimated by EIA [21] and the National Institute for Occupational Safety and Health [28] to be exposed in all commercial building conditions for two reasons: (1) they limited their consideration to workers only and did not consider the total occupant (i.e., visitor, patient, student, audience) to employee ratios, and (2) they did not consider the probability of adverse exposures in both residential and other indoor facilities.

Current Drivers for Building Performance and Stakeholders

The performances of buildings have been driven by myriad influences and agendas advocated by stakeholders from the public and private sectors. Some of the current drivers have been grouped into three interrelated categories in Figure 3.1. Within each category is a set of drivers, any one of which may dominate decision making during any period in a building's life cycle. Historically, the drivers and their interactions have been dynamic, with changing factors and priorities.

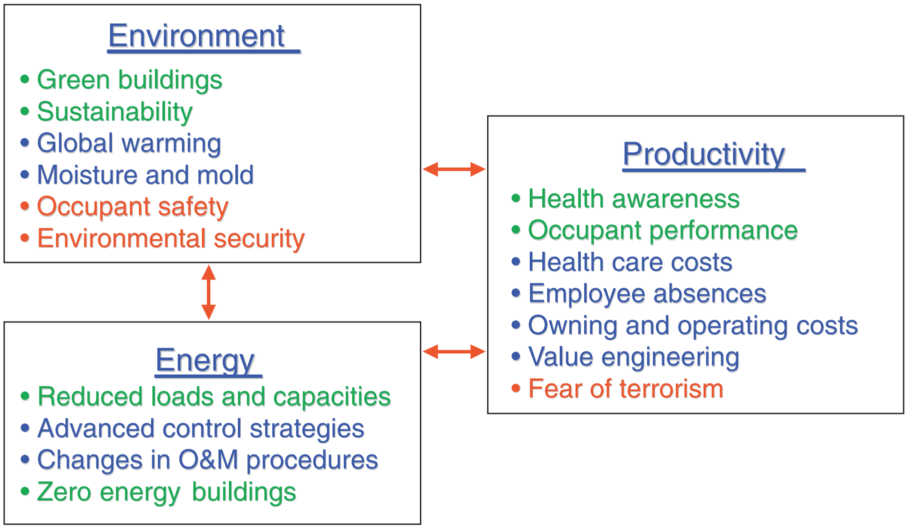

FIGURE 3.1 Three sets of current drivers: environment, energy, and productivity.

Not only are the drivers diverse and potentially conflicting, the stakeholders who advocate them often have competing interests. The large number of stakeholders[5] and their diverse interests complicate efforts to achieve a consensus approach in addressing potential means or methods to improve indoor environmental quality. Thus, a fundamental issue is: how should the changing drivers and priorities of the stakeholders be accommodated while advancing the health-protective features and practices in building design, construction, and operations?

Comparing the current drivers in Figure 3.1 with the range of stakeholders and their interests provides a perspective of the current situation regarding the need to assure or improve health protection in the various functional categories of buildings.

Several of the drivers can be synergistic with health-protective features and practices, but they can also be antagonistic. For example, to achieve certain energy, environmental, or economic objectives, some stakeholders may tend to suppress consideration of the health consequences of their decisions (e.g., maximize the use of "green" materials, minimize energy consumption, or minimize costs through "value engineering").

This comparison also reveals that accountability for health protection in nonindustrial buildings is not well defined. One reason may be that designers, consultants, contractors, and suppliers do not have the education or training to assume this accountability. Less than 2 percent of architectural and engineering curricula in the early 1990s required any formal health science courses [16]. Informal surveys conducted at seminars by the author support this finding throughout the 1990s. Moreover, similar findings are reported in curricula at schools of medicine and public health [72]. Yet licensed architects and engineers are expected, within their fields of practice, to protect the general health and safety of the general public, and licensed health care professionals are expected to diagnose and treat patients who have been affected by exposures in buildings.

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[5] A partial list of stakeholders includes owners of private or public property, agents of owners, tenants, designers and their consultants, contractors and their subcontractors, suppliers of products or services, occupants, policy makers, politicians, financiers, insurance carriers, health care practitioners, litigators and their consultants, researchers, and educators.

Economics

The National Occupational Research Agenda (NORA) report [28] presents one of the latest in a series of prospective and speculative studies on projected costs and benefits expected to be realized by improvements in control of the indoor environment [3, 25, 27, 60, 69]. Although these studies project health benefits that far exceed the projected costs of achieving them, none of the studies has been verified with actual costs and benefits, either on a micro- or macroeconomic scale.

Microeconomics

Each of the 107 million existing residences and 4.7 million existing commercial buildings in the United States has a set of microeconomic issues that are important to the concerned stakeholders. Moreover, each of the 2 million residences and 200,000 commercial buildings to be constructed in the next 12 months has another set of microeconomic issues that are important to the same or to different stakeholders. And as shown in Figure 3.1, health benefits and costs are only one of many drivers currently used to make economic decisions regarding the design, construction, or operations and maintenance of buildings.

Short of litigation, no one is currently accountable for the impact that the performance of a building has on the health of the occupants, either in the private or public sector. Therefore, within the existing building stock, maintenance is being deferred to an alarming extent [3, 25]. And for new buildings the financial incentives are for low first costs or for “green” or “energy-efficient” buildings [12, 47].

With regard to preparing for extraordinary incidents, and with few exceptions, the current position in the private and public sectors is to wait until regulations are promulgated or federal money is allocated before additional costs are invested to improve preparedness or responsiveness, unless the interventions can be justified by projections of improved health, occupant performance, or productivity.

Macroeconomics

With regard to policy, the GAO has been sounding the alarm for over a decade that major health effects are likely to occur in schools and federal buildings [3, 25]. In 2002 the President signed the Elementary and Secondary Education Reauthorization Act of 2002 (popularly referred to as the “No Child Left Behind Act”). Section 5414 of the act mandates the completion of a study by the U.S. Department of Education and submission of a report to Congress within 18 months of enactment characterizing the problems in unhealthy schools at the K-12 levels, together with recommendations to Congress for remedial actions. Unfortunately, this was an unfunded mandate, and little has been done to move this work forward. And it is too early to predict what the disposition of the GAO report identifying federal real property as a governmentwide high-risk area will be.

Available Data

An extensive international body of scientific, technical, and marketing literature now exists that supports the interests and drivers of the various stakeholders. As reported in 1998 [15] and presumed to still be valid today, a small percentage of this literature is the result of careful scientific research, in which effective experimental designs have been used to obtain original data in laboratory or field studies. A greater percentage of this literature consists of reanalyses of the results from the original studies, speculative studies based on those analyses, and anecdotal results derived from investigations of complaints. And an even greater percentage of the literature consists of marketing reports based on surveys and testimonials. Moreover, the terminology found in the literature is frequently confounded or not clearly defined. For example, “measures” of human response (e.g., discomfort complaints, symptoms), occupant performance, and productivity are often used interchangeably [15], and the concept of life-cycle costing has become suspect because of the uncertainties in the assumptions needed for the calculations.

Additional credibility challenges have been experienced since the terrorists attacks on the World Trade Center and the Pentagon on September 11, 2001, and the subsequent anthrax incidents in October and November 2001. As a result of these attacks, information was immediately promulgated in the news media that outdoor air intakes should be closed, air-conditioning systems should be shut off, and high-efficiency filters should be installed. And during an elevation in the alert status promulgated by the U.S. Department of Homeland Security in February 2003, the general population was advised that health protection should include the use of duct tape and plastic over doors and windows.

Building Codes and Standards

In practice, this literature has formed the foundation for building codes, governmental regulations, standards, and guidelines that express the "standard of care" expected by a community for the design, construction, and operation of buildings. However, this "standard of care" does not currently include health protection, although the general public expects this protection.[6]

Local building codes are often derived from model codes promulgated by organizations such as the International Code Council [4] and the National Fire Protection Association [5]. These model codes, in turn, are developed from consensus processes involving review and interpretation of available standards and guidelines, literature, and professional experience. Because a credible body of data exists pertaining to catastrophic failures of building structures and systems, and the resultant casualities, building codes primarily address structural and "life-safety" issues. However, with the exception of plumbing and water quality criteria, building codes seldom address "health" issues. Moreover, building codes primarily address design and construction issues and are enforced by "permitting" and "inspection" processes. With the exception of fire-safety codes, which are enforced by fire marshals within a community, building codes seldom address building operations. Fundamental reasons why health protection is not more predominantly addressed in building codes may be that pathogenic effects usually occur over extended periods of exposure (i.e., chronic vs. acute effects); individual susceptibilities and other exposures confound the linking of documented adverse health effects to specific building features and practices; and other competing interests (e.g., professional liability) create barriers to establishing a health basis for building codes.

Standards and guidelines are most notably promulgated by nationally recognized technical and trade organizations, such as the American National Standards Institute [6], the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [7], ASTM International (formerly the American Society for Testing and Materials) [8], the Air-Conditioning and Refrigeration Institute [9], the North American Insulation Manufacturers Association [10], the Sheet Metal and Air-Conditioning Contractors National Association [11], and the U.S. Green Building Council [12]. Although they do not carry the weight of enforcement that is associated with building codes and government regulations, they serve as a foundation for building codes and regulations, and compliance with them may also be included as a contractual requirement on specific projects. These standards and guidelines, which are generally developed from consensus processes involving professional experience together with review and interpretation of available literature, provide guidance pertaining to several of the drivers shown in Figure 3.1. Like building codes, guidance on control for health effects is rarely provided in building standards and guidelines. Rather, consideration of health effects is almost always explicitly excluded, even those that are most germane to IEQ. Moreover, the large number of standards and guidelines promulgated by these organizations with regard to environmental quality, energy, and economics contain actual or potential conflicts in various documents, within and between organizations.

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[6] Architects and engineers are licensed in their fields of practice by the states to "protect the health and safety of the general public."

CURRENT STATE OF KNOWLEDGE ABOUT BUILDING SYSTEMS AND ENVIRONMENTAL CONTROLS

Criteria and Measurements for Environmental Control

To achieve the primary purposes of buildings, methods of environmental control are needed. The objectives of environmental control may be expressed as (1) prevention of adverse health and safety effects and (2) provision for desired conditions of human response, occupant performance, and productivity. These objectives can be achieved by simultaneously controlling within "acceptable ranges" exposures of physiological receptors that sense four primary environmental stressors: thermal, contaminant, lighting, and sound. A rational model that links measures of human responses and exposures with system and economic performance parameters was introduced in 1993 [29] and extended in 1998 [30] to differentiate between measures of human response, occupant performance, and productivity. This extended model, shown in Figure 3.2, is used here as a focus for discussion of current knowledge regarding criteria and measurements of exposure, human response, occupant performance, productivity, and safety and security.

Exposures

Four sets of *exposures* are typically considered within the *physical factors* for indoor environmental control purposes: thermal, contaminant, lighting, and acoustics. Each of these sets is related to physiological receptors, and each is intended to be passively or actively controlled to within specified ranges by systems (e.g., HVAC, natural ventilation and lighting, "artificial" lighting, and architectural and electromechanical acoustics). Measurable and controllable variables and recommended ranges of their values have been generally adopted for the

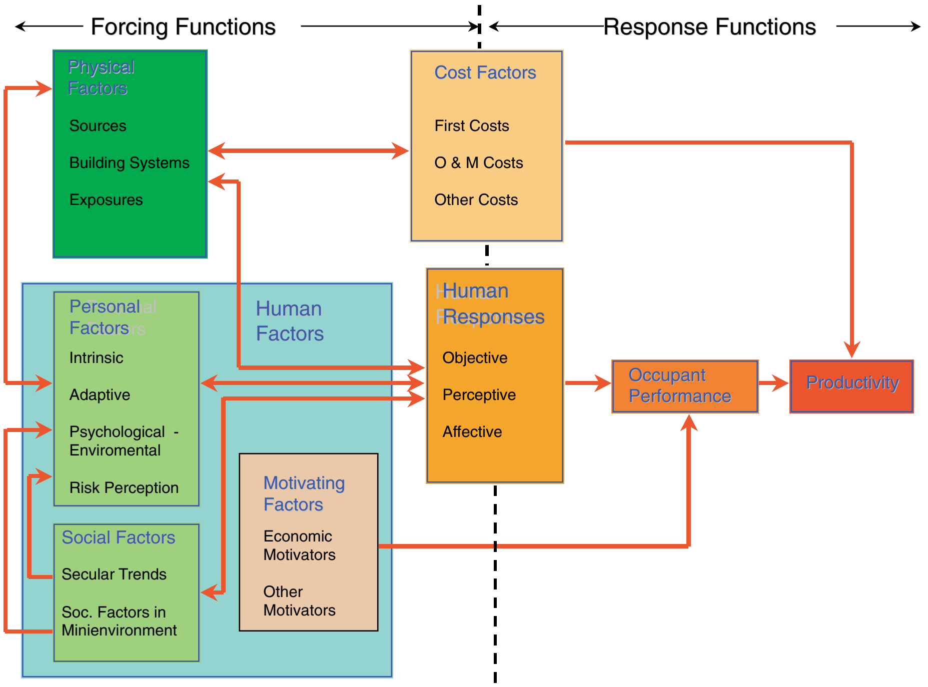

FIGURE 3.2 An extended rational model for environmental control [30].

thermal (i.e., temperature, humidity, air speed), lighting (i.e., luminance, frequency), and acoustic (i.e., sound pressure, frequency) parameters [31-33]. All of these variables are associated with energy stressors[7] and feedback control of physiological and physical systems.

A similar set of measurable and controllable variables for the constellation of contaminants known to be present in nonindustrial environments has yet to be established or associated with mass stressors,[8] although some attempts are being made through the introduction of terms such as decipol units [34], total volatile organic compounds (TVOCs) [35], and metabolic volatile organic compounds [36]. Because of a lack of sufficient knowledge to characterize indoor air quality in nonindustrial environments in terms of measurable and controllable variables, indirect or open-loop control is generally relied on today. This control is usually in the form of supplying specified rates of outdoor air for ventilation [13] and monitoring for a variety of concentrations to which occupants may be exposed,[9] including particulate matter (i.e., PM_{10} or $PM_{2.5}$ [37], pet and dust allergens [38], carbon dioxide, organic and inorganic chemicals [39], humidity, and microbials [40]. Recent concerns regarding measurable and controllable mass stressors associated with intentional releases of chemical and biological agents have intensified the need for rapid means of detection and control, as the deleterious or fatal concentrations of these agents are substantially less than those typically characterized as indoor air contaminants [17, 19]. Currently physical sensors are not commercially available or sufficiently reliable and responsive for this use. Therefore, current recommendations are to depend on open-loop methods of preparedness and control [18, 20].

Studies have also been reported that indicate significant interactions of environmental stressors. Rohles et al. [41, 42] reported that changes in lighting frequencies (i.e., warm-cool colors) and acoustic frequencies affect thermal perceptions. Jannsen et al. [43] reported that changes in carbon dioxide concentrations affect thermal perceptions. Cometto-Muniz [44] and Wargocki [45] reported that changes in temperature and humidity conditions affected odor perception. More recently, Woods et al. [46] showed evidence of two- and three-way interactions between illumination, sound pressure, carbon dioxide, and PM_{10} levels in classrooms. Thus, total exposure to energy and mass stressors (see footnote 2) is likely to affect both physiological responses and physical system performance.

Human Responses

Three sets of human responses parameters are typically considered: perceptive, affective, and objective (Figure 3.2). The perceptive and affective responses may be with regard to the environment—for example, the room is warm (environmental-perceptive) or the room is “acceptable” (environmental-affective)—or with regard to a personal state—for example, “I am warm,” “I have a headache” (personal-perceptive), “I am uncomfortable,” “I am sick” (personal-affective). The objective responses, which are also related to the personal state (personal-objective), are those that are assessed using clinical tests (e.g., clinical signs of illness or disease). With the possible exception of the personal-objective responses, measures for human responses are obtained by surveys, questionnaires, and interviews. However, as indicated in many of the forms available in the literature, the inquiries in these instruments often confound the responses. Moreover, building codes and standards typically address only the environmental-affective responses (e.g., 80 percent “acceptability,” 80 percent “visual comfort probability,” 20 percent “dissatisfaction”) [13, 31, 47], whereas complaint investigations focus on personal-perceptual and personal-affective responses.

Human responses are influenced not only by the physical factors (i.e., exposures) but also by other sets of human factors (i.e., personal factors, social factors). Therefore, without information regarding personal and social

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[7] Energy stressors of the physiological receptors include convective (sensible and latent) heat exchange and radiation exchange in the infrared (i.e., thermal), visible, and audible spectra.

[8] Mass stressors of the physiological receptors include particles, gases, and vapors that are characterized by size (e.g., molecular weight, Angstrom, micrometer) and concentration (e.g., number or mass per unit volume or surface area).

[9] References 37-40 describe some new methods of measurement, as reported at Indoor Air 2002.

factors, reports that claim to show relationships between exposures and human responses may be confounded. An example of this confounding is the issue faced by the Centers for Disease Control and Prevention's investigation of incidents regarding the attribution of infant deaths associated with exposure to *Stachybotrys chartarum* [48]. Nevertheless, significant health effects have been causally linked to indoor exposures, including development of asthma in susceptible children from exposure to dust mite allergen and exacerbation of asthma in sensitive individuals from exposure to cat, cockroach, and house dust mite allergens and to environmental tobacco smoke [26, pp. 6-10]; tuberculosis [49]; legionellosis [14, 50]; and aspergillosis and other "hospital acquired infections" [51]. Reports at a recent international conference reaffirm previous studies and indicate that symptom prevalence associated with sick building syndrome is linked to thermal, chemical, and microbial exposures [52-54], and a strong psychological component has also been recently reported [55].

Occupant Performance

Occupant performance is a different outcome measure than either human response or productivity. Occupant performance should be expressed in terms of measurable and controllable parameters that relate to the functions provided in the indoor space [30]. Traditionally, occupant performance is measured in terms of quality (e.g., errors/unit time), quantity (e.g., time required to complete task), or quality and quantity (e.g., learning outcome assessments, typing scores diminished by errors). Nontraditional measures include absences from work and "self-reported productivity" [15].

As indicated in the literature and shown in Figure 3.2, occupant performance is influenced by physical factors (i.e., exposures) and motivating factors such as salary, patriotism, and loyalty. The quantitative influence of these two factors on occupant performance is not well understood or documented in the literature. However, evidence demonstrates that the influence of the motivating factors can overwhelm the influence of the physical factors on occupant performance (e.g., trauma centers, command centers). Confounding or not controlling for the effects of motivating factors and other human factors may indicate why the reported effects on occupant performance continue to be so diverse in field studies [56-60]. As demonstrated recently, fear and insecurity in occupied spaces are demotivating factors and are likely to have significant effects on occupant performance if not controlled.

Productivity

Productivity is another outcome measure that has been confounded in the literature. As objectively defined in the literature (and shown in Figure 3.2), productivity is an economic outcome measure of the value in an interventional change in occupant performance compared to the cost of achieving that change [30]. Comparable definitions are used in two recently published tools for calculating productivity [60, 61]. The weakness in both of these tools, however, is the uncertainty of the input data. As databases become more robust, the credibility of the calculated outcomes should increase. An example of how productivity analysis can be used to inform policy was presented at Indoor Air 2002. Cunningham et al. [62] explored how managed care organizations and other health insurers can estimate the potential savings they could experience by combining medication management with environmental trigger avoidance in an asthma management program.

Safety and Security

Since the terrorist attacks of September 11, 2001, and the subsequent anthrax attacks that occurred in October and November of that year, three basic guidance documents have specifically addressed methods for protecting occupant health and safety from future attacks [18, 20, 63]. Each of these documents addresses the issue of assuring the preparedness of a building's health and safety, during normal conditions, and for responsiveness during extraordinary incidents. The ASHRAE guidance extends extraordinary incidents to mean naturally occurring, accidental, or intentional.

Although these documents present recommended actions, they do not provide specific criteria or recommended measures to assure compliance. However, the ASHRAE document introduces the concept of "acceptable vulnerability" and suggests a risk management approach to determining those criteria and methods of compliance. Of note, each of the factors and response functions (Figure 3.2) pertains to these safety and security issues. Moreover, feedback from government agency and private-sector owners, and other stakeholders, reveals that cost-effective solutions are needed that can be justified based on improved occupant performance and productivity during normal conditions as well as preparing for health and safety responses during extraordinary incidents.

Building Features and Health Protection

The NORA report [28] used the phrase "health-protective features" to describe components and systems that potentially affect IEQ and occupant health. These features included the "design and materials of the building (e.g., the outside envelope, air handler, ventilation distribution system, indoor surfaces) and the contents (e.g., furnishings, office equipment)." For consistency with this concept of health-protective features and to address the two primary objectives of environmental control expressed above, the following systems are discussed as they relate to the performance of the building system as a whole. This discussion includes the considerations from the NORA report but is not limited by it. Rather, this discussion of health-protective features focuses on addressing the current drivers shown in Figure 3.1 and complying with the performance criteria described above.

Structure and Envelope System

The purpose of the structure and envelope system is to provide safety and protection for its occupants at all times (i.e., during normal and extraordinary loads), cost effectively and energy efficiently. The structural components of the envelope system bear the weight (i.e., static or "dead" loads) of the building materials and the contents within the building and the dynamic (i.e., "live") loads imposed on the building (e.g., occupant, seismic, rain, snow, and wind loads). The nonstructural components of the envelope system provide for the desirable functions (e.g., entrance and egress through doorways and other passageways, visual communication and natural ventilation through windows, and aesthetic value) while providing protection for health, safety, and property inside the building. This protection is from a constellation of unwanted penetrations and intrusions (i.e., thermal, moisture, and contaminant loads; air infiltration; liquid water penetration; noise; glare, fire, and smoke; and physical security).

Based on the ASHRAE report [20], the loads imposed on the structural and envelope system may be classified as normal and extraordinary loads:

Normal loads are determined from "design" (i.e., probabilistic) conditions that are expected to occur on a regular basis during the lifetime of the building. The primary use of the normal load information is to select the capacities and control strategies of the structural, mechanical, and electrical systems needed to provide for health, safety, comfort, occupant performance, and productivity within the building during its lifetime.

Extraordinary loads are determined from risk assessments of naturally occurring, accidental, or intentional incidents that may occur at some time during the lifetime of the building [20, 63]. The primary use of the extraordinary load information is to assure that the selected system capacities are sufficient and to modify the control strategies as necessary to protect occupant health and safety during extraordinary incidents (e.g., safe egress, isolation of affected area).

Structural and envelope systems seldom consist of monolithic components. Rather, they are comprised of many multifunctional materials and connections and may or may not contain wall, roof, or floor "cavities." The properties of these materials and connections should include the following health-protective features: thermal resistance and capacitance; resistance to air infiltration; resistance to water vapor, particulate, and gaseous contaminant transmission; fire resistance; resistance to mold growth; acoustic and light absorption and reflectance; low chemical emission; durability; toughness; maintainability; and aesthetic quality. The values for these properties are available in design handbooks and in manufacturers' literature. Selection of the appropriate materials and connections, which is usually accomplished by agreement of the several stakeholders (e.g., owner, architect, contractor, supplier, building code administrator, tenant, occupant), has significant economic consequences [64, 65]. Moreover, the selection of these materials and connections significantly affects the normal and extraordinary loads that must be controlled by other systems.

Heating, Ventilating, and Air-Conditioning (HVAC) Systems

The purpose of HVAC systems is to provide for the health, comfort, and safety of the occupants at all times (i.e., during normal and extraordinary loads), cost effectively and energy efficiently. With the exception of radiant heating and cooling processes, air movement is the fundamental method used by HVAC systems to control the temperature, humidity, contaminant concentrations, and pressurization in occupied spaces. The capacities and complexities of HVAC systems vary widely from small self-contained room air-conditioning units to sophisticated systems used in therapy and in hostile environments (e.g., surgical suites, chemotherapy treatment facilities, burn-patient treatment facilities, biocontainment research laboratories, submarines, and satellites). Yet the function of all HVAC systems is common: to provide, in response to envelope and internally generated thermal and contaminant loads, the required heating and humidification, ventilation and air cleaning, cooling and dehumidification, and air distribution and pressurization to maintain thermal and indoor air quality exposures within "acceptable ranges."

Controllability may be the most important health-protective feature of HVAC systems. Design or peak loads are imposed within the basic zones of control for relatively short periods of time during normal conditions. For example, design summer and winter conditions for thermal loads are typically assumed to occur for less than 5 percent of the year [67], design dew-point conditions may occur for less than 2 percent of the year [67], and peak periods of pollen and other allergen releases may occur for only short periods of time (usually during moderating weather conditions). Therefore, for nearly 90 percent of the time during normal conditions, the HVAC system capacities do not match the partial loads, and controls are used to reduce the system outputs by cycling components on and off or by modulating motors on fans, dampers, and valves. Without adequate control to ensure that the exposure criteria are maintained during these part-load conditions, the risk of adverse health effects increases.

Preparedness of HVAC systems to respond to extraordinary incidents is also a vital control function. In cases where accidental incidents (e.g., fires, floods, chemical spills) or intentional incidents (i.e., external or internal releases of chemical, biological, or radiological agents) occur, life-safety control strategies for the HVAC systems provide for isolation of the release zone, compartmentalization, emergency use of redundant and supplemental systems, and safe egress [5, 20, 63]. For fire and smoke control, the life-safety codes require that certain HVAC systems be identified for such use and provided with emergency, stand-by power.

Lighting and Acoustic Systems

The purpose of lighting and acoustic systems is to provide for the comfort and safety of the occupants at all times (i.e., during normal and extraordinary loads), cost effectively and energy efficiently. In several respects, the methods of control for lighting and acoustics in occupied spaces are similar: (1) both systems depend on reflective and absorptive characteristics of the surfaces within the occupied space; (2) both require control of intensities over frequency spectra; (3) both have natural and amplified mechanisms of control; (4) both have characteristics that are associated with symptoms of sick building syndrome (e.g., headaches; fatigue; nausea; dizziness from excessive glare, sound, and vibration); (5) both contribute significantly to the well-being of society (e.g., art galleries, museums, concert auditoriums, theaters) as well as to functional applications (e.g., homes, schools, offices, public assembly, hospitals); and (6) both have strong interactions with envelope and HVAC systems (e.g., lighting loads, noise reduction and transmission).

During extraordinary conditions, lighting and acoustic systems also serve vital functions, as they provide guidance and enable egress for occupants and entry for first responders. For fire and smoke control, life-safety codes now require certain lighting and acoustic systems to be designated for this purpose and to be provided with emergency standby power.

Enclosure Systems and Furnishings (Open- and Closed-Occupancy Areas)

The purpose of enclosure systems and furnishings is to provide for the comfort and performance of the occupants during normal conditions, safely and cost effectively. Enclosure systems include fixed and movable walls and partitions, ceilings, and flooring that define spaces for occupancy in each of the building categories shown in Table 3.1. The sizes of enclosure systems vary widely: from open-office modules of approximately 36 ft^2 (telemarketing and some administrative work), to 150 ft^2 for management offices, to 1,000 ft^2 for classrooms, to large public assembly areas. Furnishings for these occupied spaces include built-in, free-standing, and wall-hung desks, bookcases, and cabinets; chairs, computers, printers, and other office equipment; and carpeting, wall coverings, and personal items. Enclosure systems and furnishings contribute to thermal, lighting, acoustic, and contaminant loads that must be dissipated by the HVAC systems [66].

As a means to enhance worker performance, flexibility of the enclosure systems has been emphasized [67], including the ability to provide electrical power, HVAC, and communications wiring to these enclosure systems. As a result, most commercial buildings have been provided with ceiling plenums that contain supply air (and sometimes return air) ducts, power and communications wiring, and piping for plumbing and fire protection (sprinkler) systems. More recently, a trend toward the use of raised floors to provide easier access to electrical power and communications wiring has been noted. Moreover, some of these raised-floor systems are now providing underfloor air distribution (UFAD) [67, 68].

The health effects from exposure in these enclosure systems, especially the UFAD systems, are not yet known. Although a preliminary set of field studies [68] reveal that the frequencies of occupant discomfort complaints and symptoms of sick building syndrome are not dissimilar to those in other commercial buildings, concerns from consulting engineers and contractors have been expressed that the pathways from contaminated surfaces in unducted floor plenums to the breathing levels of occupants is much shorter than in conventional systems. Other concerns expressed about UFAD systems by consulting engineers and contractors are that isolation and compartmentalization are difficult for fire protection and, more recently, for protection against accidental or intentional chemical or biological releases.

Building Automation Control Systems

The purpose of building automation control systems (BACS) is to provide a centralized location where the performance of buildings can be evaluated. Conventional feedback control systems seldom presented reliable information at a centralized location, until computerized systems were introduced in the 1970s. However, the sensors that provided information to the centralized panels were usually separate from the sensors used for feedback control. This limitation was reduced with the introduction of direct digital control in the 1990s through which sensors were used for simultaneous control and documentation. Today, it is practical to have centralized building automation control systems that focus on thermal and lighting control and energy management (e.g., optimal stop-start cycles). However, indoor air quality control remains limited by the few types of real-time sensors available (e.g., carbon dioxide, volatile organic compounds) and their reliability. Moreover, practical methods of indoor air quality control remain limited to dilution (e.g., increased ventilation) and particulate air cleaning (filters).

Currently, building codes do not permit the integration of fire and life-safety control systems with BACS or energy management systems, other than fan and damper interlock controls. As the demand for improved preparedness for extraordinary incidents increases, new sensor technology is anticipated that will allow more rapid system responses, such as zone isolation, compartmentalization, and decontamination. Also anticipated are integrated control technologies that will monitor and control for improved health, occupant performance, productivity, and security.

BARRIERS TO IMPROVED BUILDING PERFORMANCE

Six barriers that may obstruct consideration of IEQ in the design, construction, and operations of buildings were listed in the NORA report [28]. This section extends consideration of these barriers into a set of barriers that impede implementation of health-protective features, practices, and policies: (1) disaggregated industry, (2) lack of accountability, (3) lack of credible data, (4) inappropriate value engineering, (5) deferred maintenance and other competing strategies, and (6) concerns regarding liability.

Disaggregated Industry

The building industry is the product of a long history and has its roots in indigenous methods. Many of the theories and practices used today to design, construct, and operate buildings have evolved from these historic processes. As a result, most of the 107 million residential and 4.7 million commercial buildings in the existing stock [21, 22] serve as their own prototypes and have their own individualized sets of goals and expectations that have been defined and modified by the stakeholders associated with them. Whether or not these goals and expectations are documented (e.g., available as plans, specifications, and operating manuals), each building's performance is dependent on the knowledge, skills, and influences of the stakeholders. Thus, the large number and types of buildings, the diversity of their stakeholders, and their conflicting drivers present significant barriers to forming a consensus approach toward the development of health-protective features and practices for the design, construction, and maintenance of buildings in the United States.

Lack of Accountability

Throughout the disaggregated building industry, barriers have been established to obfuscate accountability for the performance of buildings, especially as they affect occupant health. Examples of these barriers include:

- Designers, contractors, and operators receive little education and training in the health sciences and therefore are not generally prepared to evaluate the health consequences of their decisions.
- Building codes and standards focus on design and construction, seldom address "health" issues, and are written in "prescriptive format" for ease of determining "compliance" without the need to consider health consequences.
- Occupant health may be explicitly excluded as an issue in contracts between owners, designers, contractors, and tenants.
- Occupant health is generally avoided as an issue in project documentation: permit applications, architectural programs, project specifications, commissioning documentation, certificates of substantial completion, and occupancy permits.

Lack of Credible Data

Financial and technical decision makers have for many years questioned the quality of data that purport to relate the benefits and costs of indoor environmental exposures to health effects. The credibility barriers include:

- A dearth of peer-reviewed scientific studies based on statistically valid experimental designs that test the relationships between measured indoor environmental exposures and measured health consequences.
- A plethora of prospective and speculative reports on the projected costs and benefits expected to be realized by improvements to indoor environmental quality. Typically, these reports are based on assumptions with questionable validity.
- Anecdotal reports and testimonials that claim unsubstantiated health costs and benefits associated with exposures to indoor environments.

Inappropriate Value Engineering

Value engineering (VE) is a process used in the private and public sectors for the purpose of identifying potential cost savings in the design and construction processes. For example, the GSA defines VE as "an organized effort directed at analyzing designed building features, systems, equipment, and material selections for the purpose of achieving essential functions at the lowest life cycle cost consistent with required performance, quality, reliability, and safety" [70]. The GSA uses VE during both the design and construction phases of a project.

Value engineering, if performed appropriately, can realize significant improvements in system performance with expected beneficial health consequences. However, if value engineering is used only as a means to reduce the first costs of a project, it is likely to be a significant barrier to implementation of health-protective features and practices.

Deferred Maintenance and Other Competing Policies

Three significant barriers to the implementation and assurance of health-protective features and practices occur during the operational phases of a building's life: (1) premature occupancy during substantial completion, (2) occupancy during interventions, and (3) occupancy during deferred maintenance. Each of these barriers may be inadvertently or intentionally employed to reduce costs without consideration for adverse health consequences.

Substantial completion is defined by the American Institute of Architects as "the stage in the progress of the Work when the Work or designated portion thereof is sufficiently complete in accordance with the Contract Documents so that the Owner can occupy or utilize the Work for its intended purpose" [71]. With regard to health-protective practices, proper execution of the Certificate of Substantial Completion is critically important, as this is the first time that occupants are exposed in the yet-to-be-completed construction.

Premature occupancy at substantial completion is not an uncommon cause of adverse health effects and has been the subject of litigation cases. Commissioning and diagnostic procedures may be used to minimize the risk of premature occupancy during the substantial completion period. Furthermore, accountability for the health consequences of occupancy during substantial completion also minimizes the risks to all stakeholders.

After the initial move-in period, tenant turnover (i.e., "churn rate") may be 50 percent or more in some buildings [67]. As a result, renovations and changes in system performance occur frequently. During this period, the building owner or manager may institute proactive maintenance programs, such as preventive or predictive maintenance, rely on reactive maintenance, or do no maintenance. Moreover, this is the period when overaggressive energy management procedures or cost reductions in operations and maintenance (e.g., deferred maintenance) procedures are most likely to manifest as "building degradation," such as insufficient ventilation or moisture incursion and subsequent mold growth [3, 25-27].

Also, at any time during its operational period, interventions may be implemented through which the building or its systems are modified to meet the desired intent. This intent may be to comply with newly defined performance criteria or to reestablish compliance with the performance criteria in the original program. In some cases these interventions may consist of repairs that have no impact on occupant exposure. However, in other cases, such as replacement of walls, HVAC ductwork, or renovations of areas, the impact on occupant exposure may be significant and may require relocation during the work.

Liability

Some stakeholders report that their professional liability is a significant barrier to their implementation of health-protective features and practices. Most licensed architects and engineers who are responsible for the design of buildings and facility managers who are responsible for the performance of buildings during operations choose to carry professional liability insurance. This insurance is expensive and frequently contains exclusion clauses that limit the insured to issues that can be addressed under the policy. Indoor environmental issues, generally, and health issues, specifically, are most frequently excluded from the policies. Thus, the exclusions in these policies are major barriers to implementing health-protective features and practices in the design, construction, and operation of buildings.

ABOUT THE PRESENTER

James E. Woods, Ph.D., P.E., Fellow ASHRAE, is the executive director of The Building Diagnostics Research Institute, Inc., Chevy Chase, Md. For more than 40 years, he has practiced, taught, and conducted research in subjects related to indoor environmental quality, human responses, energy utilization, and productivity in office buildings, public assembly and monumental buildings, hospitals, schools, residences, laboratories, and commercial aircraft. Results from these studies have been reported in more than 150 technical papers, six books, and two patents. He recently served as chairman of the ASHRAE Presidential Ad Hoc Committee on Building Health and Safety Under Extraordinary Incidents, and is now serving as an ASHRAE representative to The Infrastructure Security Partnership (TISP) Steering Committee.

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4

Lighting: Research and Findings

Mark Rea

Lighting is often forgotten in discussions of indoor environmental quality and building occupants' health, yet it has been shown to affect both health and productivity. There are two biological systems by which light can affect human performance and health: the visual and the circadian (see Figure 4.1). The circadian system involves biological rhythms that repeat at approximate 24-hour intervals.

To understand the impact of light on the human condition, one has to break it down into its components: intensity, spectrum, distribution, timing (when it is received), and duration. One then needs to understand where and how these light components are processed in the brain.

We understand the visual system well in terms of the effects of light on both appearance (what things look like) and visual performance (how well visual information is processed). The visual system is a very quick remote-sensing mechanism that alerts us to changes in the environment and enables us to identify friend or foe.

The circadian system is one that has been long known in plants and animals. However, it is only in the past 20 years that we have begun to take a serious look at the impact that light has on the daily patterns or daily rhythms of people, with the sleep/wake cycle being the most notable. Unlike the visual system, the circadian system is slow and has a very different tuning curve for electromagnetic radiation, and its sensitivity to light intensity is dependent on the time of day.

Humans are inherently a daytime species, born to be awake during the day and asleep at night. Eighty percent of the working population in North America works during the day, while 20 percent works on night shifts.

For a large majority of the population working in buildings, lighting for vision during the day is adequate. In part, this is because people have very flexible visual systems. If we examine the range of light levels that illuminate buildings, we see that of the 16 log unit range in sensitivity only 4 log units are used with electric lighting (see Figure 4.2).

Out in the real world, people can often adjust to their environments. Consider, for instance, that most of us adjust our computer displays more for how we want people to meet us when they enter our office than for lighting conditions. We may, for example, have our monitor up against a bright window or have it turned so that the window image is actually reflecting off the screen.

Figure 4.3 shows how people adjust their posture in response to the available light. The farther they are from the light, the closer they hold the reading materials to maintain a constant ability to read. Experiments in the laboratory similarly show that under dim conditions people will adjust the eye-to-task distance, that is, move closer to the task. The visual system combined with a flexible body provides us with the ability to adapt to the lighting environment.

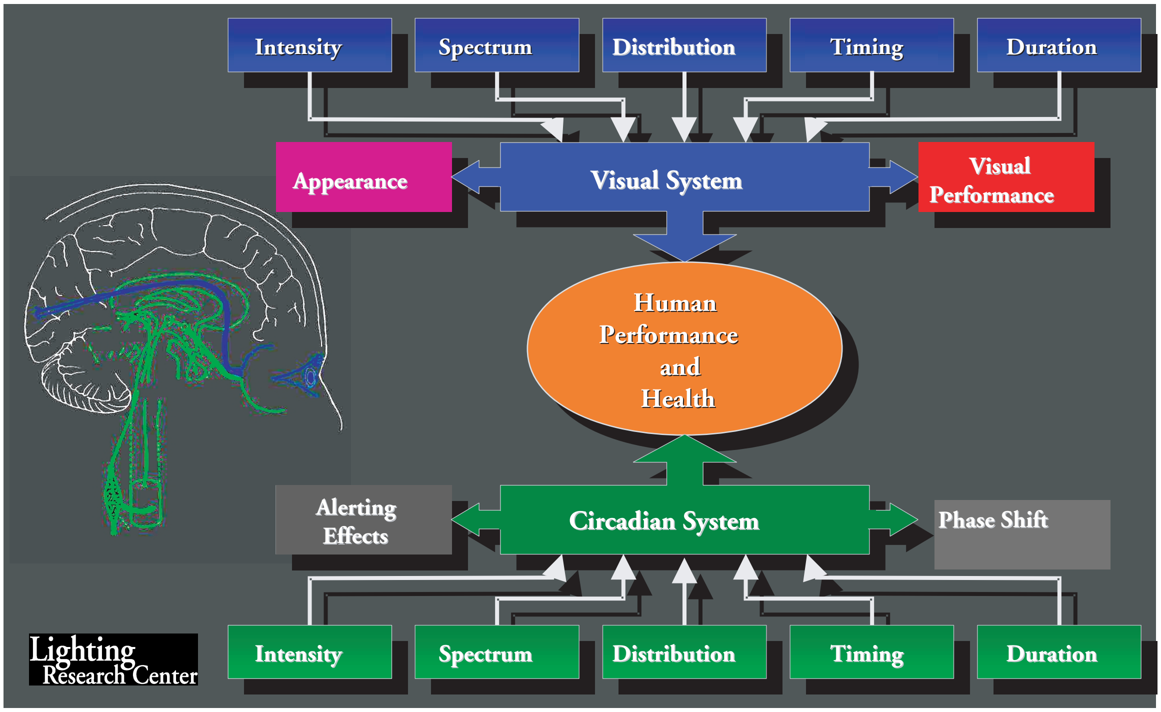
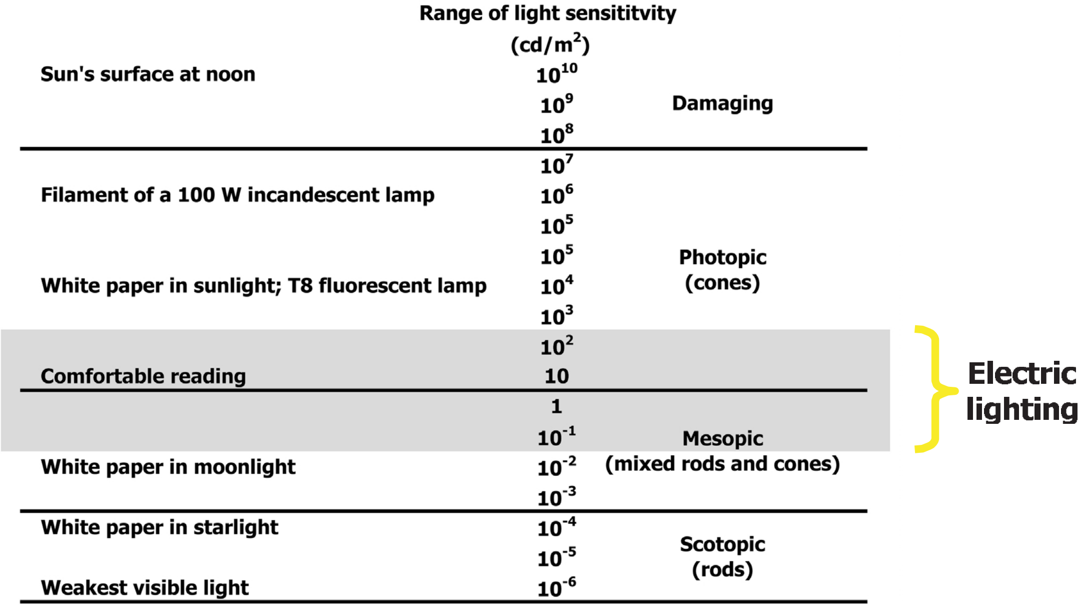


FIGURE 4.1 Light as it affects human performance and health through the visual and circadian systems. SOURCE: Produced by Lighting Research Center.



	Range of light sensititvity (cd/m^2)		
Sun's surface at noon	10^{10}		
	10^{9}	Damaging	
	10^{8}		
	10^{7}		
Filament of a 100 W incandescent lamp	10^{6}		
	10^{5}		
	10^{5}	Photopic (cones)	
White paper in sunlight; T8 fluorescent lamp	10^{4}		
	10^{3}		
	10^{2}		Electric lighting
Comfortable reading	10		
	1		
	10^{-1}	Mesopic	
White paper in moonlight	10^{-2}	(mixed rods and cones)	
	10^{-3}		
White paper in starlight	10^{-4}		
	10^{-5}	Scotopic (rods)	
Weakest visible light	10^{-6}		

FIGURE 4.2 Range of human sensitivity to light together with the range of luminances provided by electric lighting. SOURCE: Robert Sekuler and Randolph Blake. *Perception*. New York, McGraw-Hill, third edition, 1994.

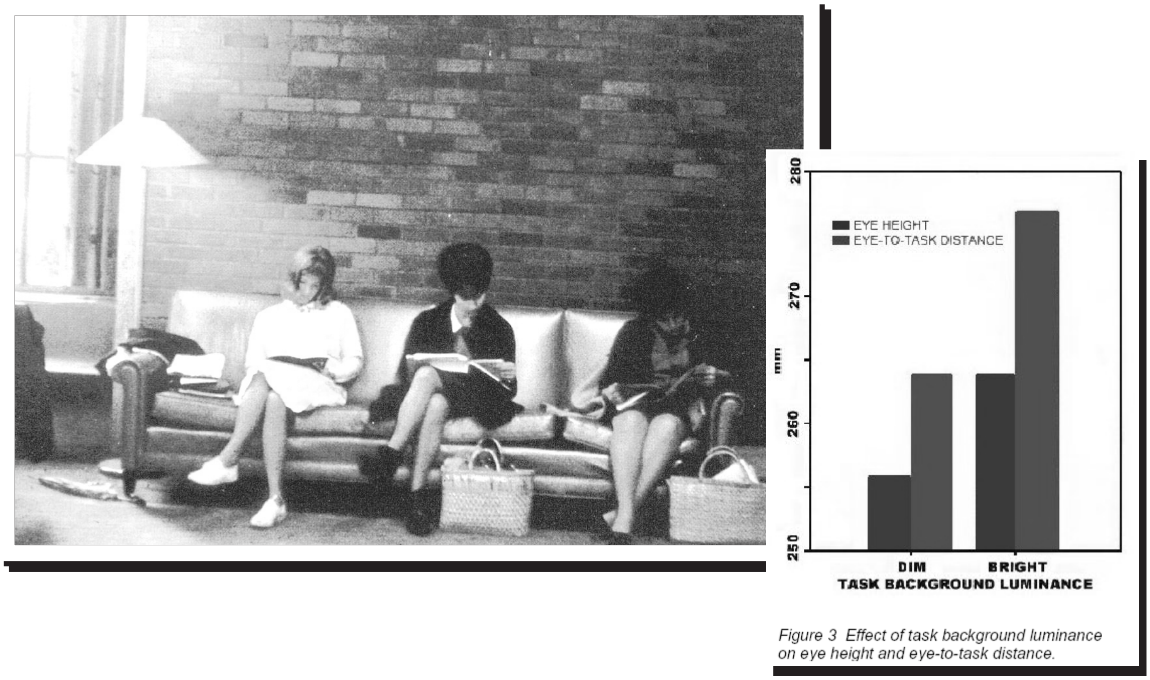


FIGURE 4.3 Lighting levels and their impact on posture. SOURCE: Photo by Murray Milne, University of California, Los Angeles. Provided by Hayden McKay, Hayden McKay Lighting Design, New York, N.Y. Chart reprinted courtesy of the Illuminating Engineering Society of North America, *Journal of the Illuminating Engineering Society* 15(1):235.

There is an important caveat to the statement that lighting is adequate for the majority of the working population. It is related to the fact that the second leading cause of death on the job in the United States is homicide. Research has shown that bright exterior lighting is associated with a significant reduction in the risk of being killed on the job, which is certainly a health-related impact. So we should think about more than just office workers when discussing lighting and health. There are other lighting applications to consider, including security and egress. Stair lighting is one example; trips and falls resulting from inadequate lighting result in many injuries in the workplace.

Normal aging is another factor to consider in studying lighting, indoor environmental quality, and workers' health and productivity. Over the past 100 years there has been a significant improvement in the life expectancy of people, from 47.3 years for those born in 1900 to 77.2 years for those born in 2003, depending on race and gender. Health care and life expectancy are improving, and the number of older people in the workforce is increasing.

Normal aging involves optical changes before age 65 and neural changes after age 65. One optical change, presbyopia, is the inability to focus on near objects. People over age 45 usually show symptoms of presbyopia. Many use optical aids to focus near objects. This situation implies that without eyeglasses their ability to lean closer to tasks is compromised, so good lighting becomes more important.

The second optical change is loss of retinal illuminance and reduced retinal contrast. As a person ages, the crystalline lens of the eyes yellow and have less optical fidelity. Figure 4.4 simulates the difference in visual clarity of a 30-year-old person and someone who is 75. To the older person, a medicine cabinet, room, or other objects would appear darker and hazier.

After age 65, vision deteriorates as a result of neural as opposed to optical changes. Some people develop photophobia, a painful sensitivity to strong light. For others neurological changes result in a reduced visual field (see Figure 4.5).

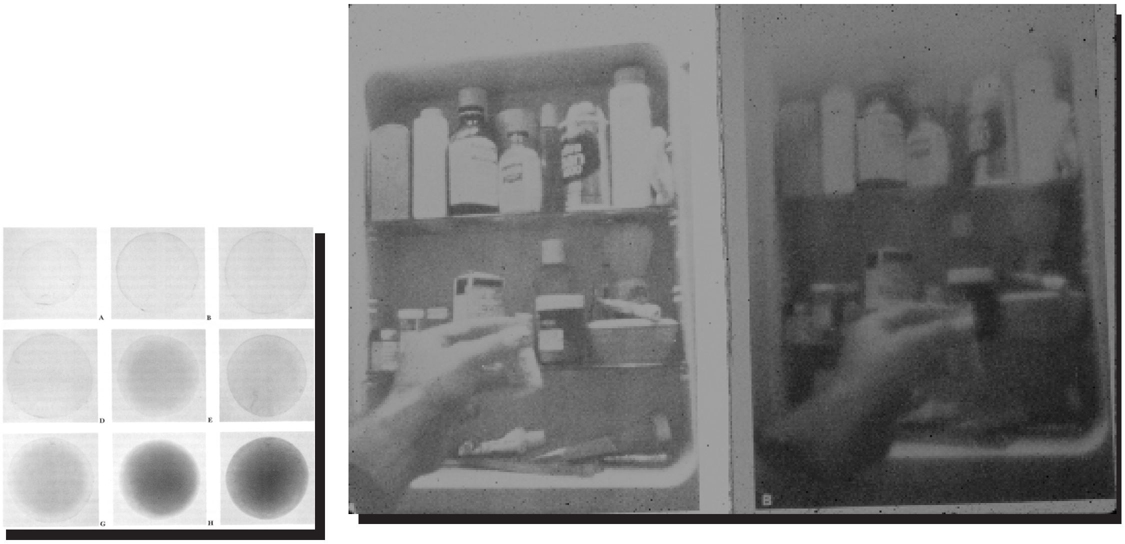


FIGURE 4.4 Simulated age-related loss of retinal illuminance and reduced retinal contrast together with age-related changes in the crystalline lens. SOURCE: Reprinted and adapted with permission of Leon A. Pastalan. Classification system for yellowing of the lens. © Lighthouse International.

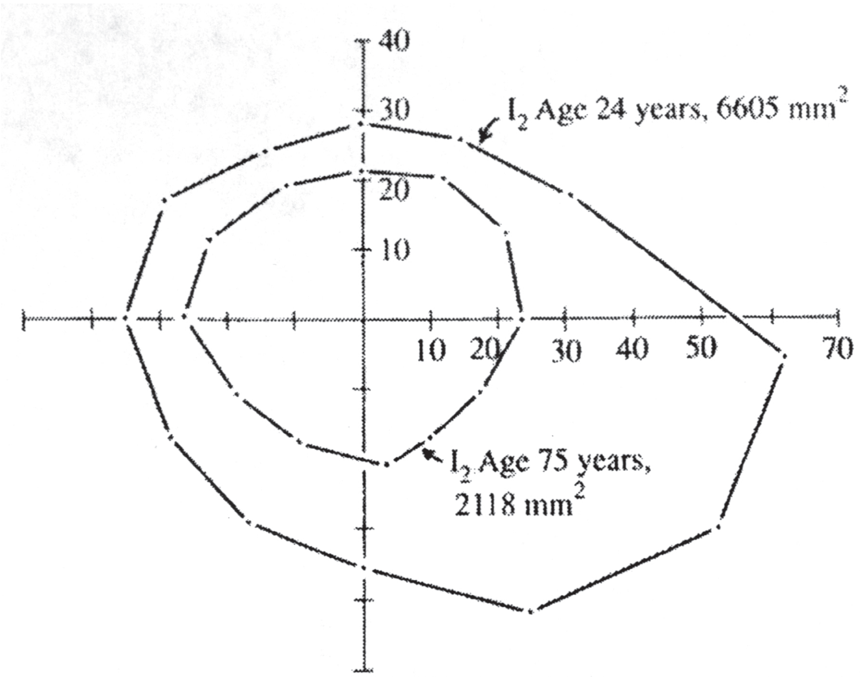


FIGURE 4.5 Aging and central visual field area. SOURCE: Reprinted with permission from D.T. Williams, 1983, Aging and central visual field area, *American Journal of Optometry and Physiological Optics* 60:888-891. American Academy of Optometry.

Loss of peripheral vision affects seniors both indoors and in office environments, where a slight ramp or an uneven surface can result in trips and falls. Senior drivers are also more likely to have an accident at an intersection because they cannot readily detect objects in their peripheral field of vision. More serious age-related diseases of the eyes include glaucoma, macular degeneration, and diabetic retinopathy.

Circadian rhythms comprise a new area of study that is profound in its implications for building practices. Light is the primary synchronizer of circadian rhythms. We actually have a circadian pattern that is about 24 hours and 20 minutes. Every morning when we awake, we reset our biological clock through light. This system requires a very high sustained light level to tell the body it is really daytime. If someone works in a mine, for example, that person's body will go out of synchrony with daily solar light and dark phases.

Current office lighting levels tend to be at the low end with regard to regulation of circadian rhythms. During the winter months, people sitting in an interior office are potentially in biological darkness all day. Those sitting next to a window, in contrast, probably receive enough light to activate their circadian system. We are not necessarily looking at a crisis, but we are observing some interesting implications.

We do know that circadian regulation in *some* populations is disrupted by inadequate light. One of the best-documented symptoms is seasonal affective disorder. Seasonal depression (also known as winter depression) is prevalent in northern latitudes, and the medical profession recognizes bright lights as a treatment.

Perhaps the impact of low light levels in buildings can have long-term effects that are not so obvious. Older people, for example, commonly have what is called phase advance syndrome. They tend to go to bed at 8:00 p.m. and rise at 4:00 a.m., roaming around before anyone else is awake. Bright light exposure in the evening will delay their sleep, allowing them to sleep later in the morning and rise at a more appropriate time.

On the other hand, about 15 to 20 percent of young adults miss significant portions of school because they do not go to sleep until 2:00 a.m. and consequently cannot get up in the morning. This condition is known as phase delay syndrome. Providing bright light in the morning and limiting light exposure in the evening can get these young adults back to more normal sleep/wake schedules.

People with Alzheimer's disease are just as likely to be asleep as they are to be awake any time during the day or night. We have used the knowledge gained about spectral sensitivity to the circadian system to provide Alzheimer's sufferers with blue light treatment early in the evening. After blue light treatment, they not only slept longer but also consolidated their sleep and were more likely to be asleep at night and awake during the day.

Lighting does matter. However, it is usually at the extremes of the population (night-shift workers, seniors, and young people) where lighting demonstrably affects the well-being and performance of workers. We do not yet understand how important light regulation is for the well-being of the majority of the population, but we are beginning to find health-related problems in segments of the population that may be harbingers to problems in the general population.

ABOUT THE PRESENTER

Mark Rea, Ph.D., is a professor of Cognitive Science at Rensselaer Polytechnic Institute's (RPI) Lighting Research Center (http://www.lrc.rpi.edu). His research interests include vision, lighting engineering, and human factors. Prior to joining the RPI faculty, Dr. Rea was a senior research officer and manager of the Indoor Environment Program of the Building Performance Section at the National Research Council of Canada. He is a fellow of the Society of Light and Lighting of the United Kingdom, and is a member of the Commission Internationale de L'Eclairage, the Illuminating Society of North America, the Optical Society of America, and the American Association for the Advancement of Science. During his career Dr. Rea has received the Illuminating Engineering Society of North America's Medal and the William H. Wiley Distinguished Faculty Award from RPI. He holds a Master of Science and a Ph.D. in biophysics from Ohio State University.

5

Environmental Issues in Health Care Design

Derek Parker

Today I am going to address improved indoor environmental design of health care facilities and discuss the research agenda that has been developed by the Center for Health Design, a not-for-profit research and advocacy organization that I helped found about 15 years ago. In this regard, I would like to call your attention to a recent publication of the Institute of Medicine (IOM), the third in a series that began with *To Err is Human*, followed by *The Quality Chasm*, and which now adds *Keeping Patients Safe*. I believe this is the first time that IOM has treated the built environment as a legitimate treatment modality, which is a major step forward for those of us interested in the physical environment and its relationship to health and well-being.

A legitimate question to ask in this time of crisis in health care is why any health care administrator should spend any time at all thinking about the built environment. When they are dealing with severe staffing shortages, declining revenues, poor balance sheets, and falling bond ratings, why spend any time at all thinking about issues in the built environment?

The answer to that, essentially, is only if we can show return on investment. From its inception, that is what the Center for Health Design has tried to do—to promote design in health care facilities that supports positive health outcomes in a moral, ethical, and sustainable manner.

We know from our experience, though, that we have not been heard very well. So over the past five years we have taken that message one step further and looked at what happens to the bottom line of organizations in a struggling sector that takes the built environment seriously.

The Center for Health Design serves and enables a worldwide network of 25,000 physicians, nurses, interior designers, architects, and researchers with an interest in the physical environment and health outcomes. In establishing the center, we were very much influenced by Leland Kaiser's work: he believed that the hospital, as a human invention, could be reinvented at any time. In this regard, we have done a great deal of thinking about the services that patients need versus what they want. Hospital patients need to be where they are. A hospital is not a resort where people choose to come. It is a place where they come when they need care, a time of considerable stress.

For the past five years, the center has been developing a research agenda. We call the research projects "pebbles" because one of our board members visualizes throwing a pebble into a pond and seeing if the research results would ripple through the industry. It appears that this is beginning to happen.

First, understand that patients speak a different language than caregivers. Patients must resort to visual clues to assess the level and quality of care they receive. In essence, they become detectives who must sift through the torrent of clues that facilities provide about the quality of the care and the philosophy and caring attitude of the organization.

Every building tells a story. It also communicates to the staff what management thinks about their safety and welfare. A 1999 study from the IOM found that ". . . serious and widespread quality problems exist throughout American medicine. These problems . . . occur in small and large communities alike, in all parts of the country, and with approximately equal frequency in managed care and fee-for-service systems of care. Very large numbers of Americans are harmed as a result. . . ." This indicates that we have a very serious problem in this country that may be as bad or worse elsewhere. Very large numbers of Americans are harmed as a result of what is essentially a system design failure within our hospitals. The IOM stated that between 48,000 and 94,000 Americans die preventable deaths every year in American hospitals.

Figure 5.1 shows where interaction with the health care system rates as a hazardous activity. On a per-interaction basis, it is almost as dangerous as bungee jumping and mountain climbing and, because of the much higher participation rates, claims a thousand times more lives annually. Obviously, there is a very serious quality and safety issue in our hospitals.

David Lawrence, chairman of Kaiser-Permanente, has said that in his organization he is going to reduce costs by improving quality. I believe that is a worthy and achievable goal.

Figure 5.2 could be taken in almost any hospital in the United States today, and, as you'll note, it is very difficult to find the patient amid all the clutter. The photo could not have been taken in any other country because only in American hospitals is so much equipment so readily available. It is no wonder that systemic failure is such an issue.

Figure 5.3 shows the six domains from the IOM study that we at the Center for Health Design have taken very seriously. We try to look at the components of the physical environment for each of those six domains. Colin Martin expressed this idea well in *Lancet:* "Although the premise that physical environment affects well-being reflects common sense, evidence-based design is poised to emulate evidence-based medicine as a central tenet for healthcare in the 21st century." Unfortunately, this concept is not, at the moment, mainstream, but we are gradually beginning to see a relationship develop between evidence-based design and evidence-based medicine.

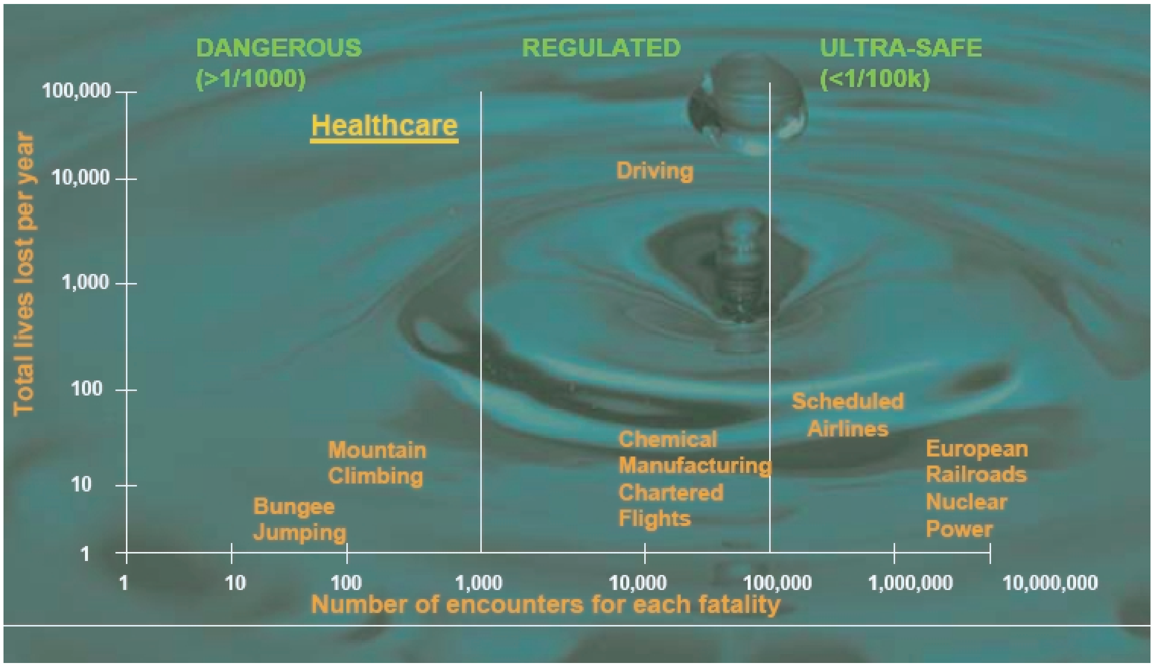


FIGURE 5.1 Fatality rates for various activities.

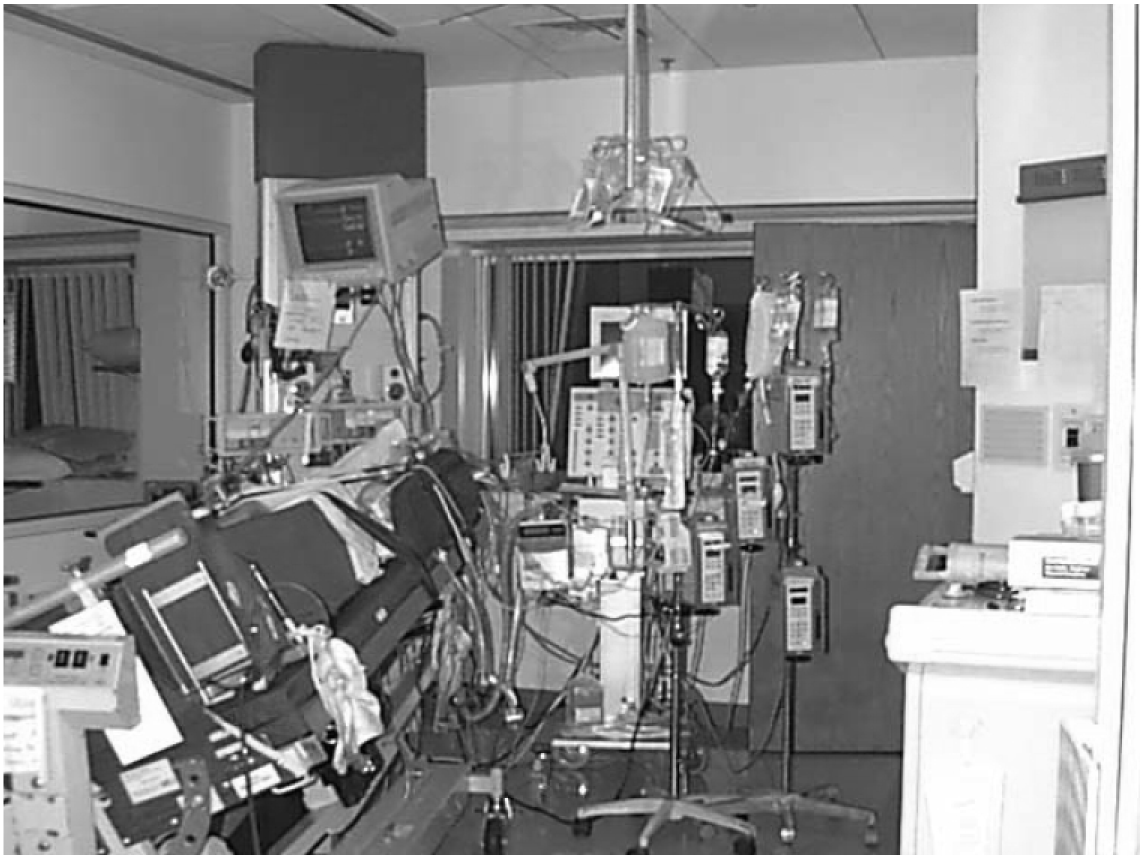


FIGURE 5.2 Typical treatment room in a U.S. hospital.

In support of the Center for Health Design, Haya Rubin of Johns Hopkins University, was retained to do a literature search on the relationships between the built environment and medical outcomes. From almost 80,000 studies she found only 84, less than one-tenth of 1 percent, that actually met any criteria for inclusion in the database. There is just not very much in the way of data or analysis to document these relationships. It was just this lack of documented evidence that led the center to initiate several projects. We had several objectives in beginning this work: to develop a research model that would produce documented research examples, to start a dialogue on the results, and to create a ripple effect through the industry. That is now happening.

CHILDREN'S HOSPITAL HEALTH CENTER

Children's Hospital Health Center in San Diego was the Center for Health Design's first "pebble." From that beginning, we now have 18 projects around the country as shown below:

- San Diego Children's Hospital
- Karmanos Cancer Institute
- Clarian Methodist Hospital
- Bronson Methodist Hospital
- Southwest Washington Memorial Hospital
- St. Alphonsus Regional Medical Center

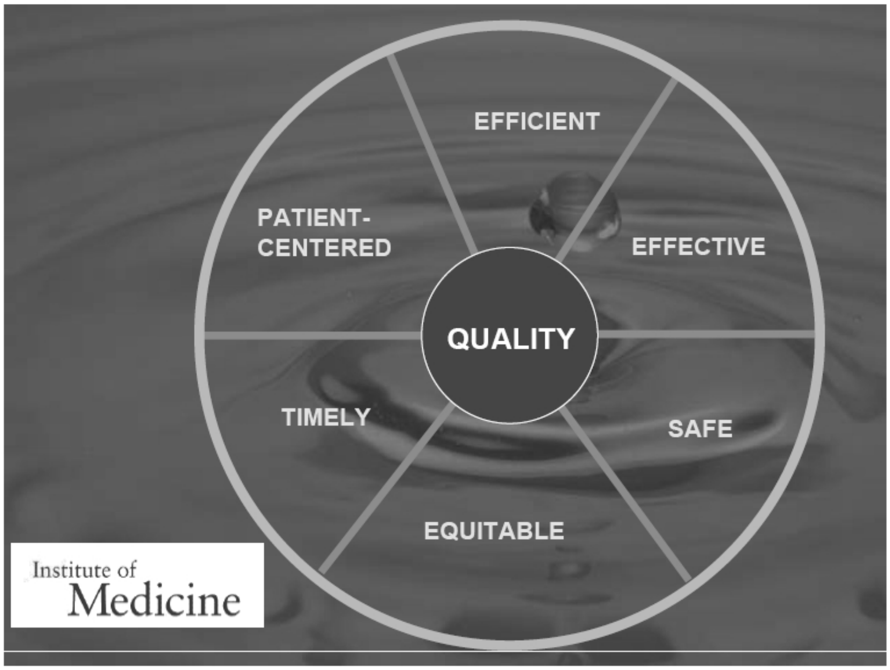


FIGURE 5.3 The six domains of health care quality.

- Weill Cornell Medical Center
- Froedtert Hospital
- Parrish Regional Medical Center
- Scott and White
- Yavapai Medical Center
- Sitrin Health Care Center
- M. D. Anderson
- Peace Health Oregon Region
- Columbia-St. Mary’s
- Affinity Health System
- Bethesda Hospital
- Banner Estrella Medical Center

These facilities are quite diverse and include women’s and children’s hospitals, cancer and cardiac specialty centers, and long-term care facilities. These projects are all being driven by senior management—the chief medical and administrative officers who want to know more about how to use the physical environment as a legitimate treatment modality.

Representatives of these 18 institutions now come together twice a year to meet and share successes, frustrations, and data in an open exchange. Nothing is secret. Stress on patients, their families, and the staff has been an important focus. We are facing a very serious staff shortage in American health care at every level, but particularly nurses, and all indications are that the situation is going to get worse before it gets better.

The research agenda has been divided into five areas: access to nature, degree of personal control, the use of positive distractions to reduce stress, social support for the patients, and environmental stressors.

We have identified multiple factors in each of these areas where we think the built environment has something to contribute. Measurement is a critical issue so that the data are meaningful and reproducible. Jim Varni, of the Center for Child Health Outcomes at Children's Hospital in San Diego, designed a matrix to arrange the data so that we can understand and communicate the results. The PedQL™ Inventory captures clinical outcomes, financial outcomes, and satisfaction outcomes at the level of a single patient, groups of patients, staff, visitors, and family.

CONVALESCENT CARE HOSPITAL

Convalescent Care Hospital seemed like a good pebble because it is a unique specialty facility. It houses 60 very fragile children who are in long-term care, all of whom are in wheelchairs, and many are blind. Even every wheelchair is different, designed specifically for the needs of a particular child. Many children have suffered abuse or accidents that caused brain damage, such as near-death drownings.

They are currently housed in a building designed for acute care adult patients, which is a totally inappropriate environment. Moving them into a new building specifically designed around their needs will give us the opportunity to observe how the same patients, with the same caregivers, families, and services, react to a change in the environment. That seemed like a great opportunity to collect some pre- and postrelocation data.

Changes in organizational behavior as the organization moves from the existing building to the new building will also be measured. We are now talking about changes in that behavior in the present building that we can put in place, try out, and move into the new building.

As an example of providing more control for patients and their families, we redesigned the wheelchair storage. Every child has a wheelchair that is now stored in the corridors, creating a safety hazard. We thought we would put garages in the corridors, so people could put their wheelchairs away, but the parents didn't like that. They think of that wheelchair as being a very personal extension of their child, and they wanted it in their control within the child's room. So we just reversed the garages, so that they are only accessible from the room. One mother looking at the plan said, "I like the concept, but I don't see anywhere where I can take my child out of the room, be out of the way but not isolated, and hold her in her fuzzy red pajamas and read her a story."

That stuck with us. So we went through the plans and found that by doing some very simple things, such as changing the door swing, moving a column, modifying some lighting, and so on, we were able to create half a dozen "fuzzy red pajama" spaces in the building without changing the cost of the building or the program.

BRONSON METHODIST HOSPITAL

The second pebble was Bronson Methodist Hospital, a new building in Kalamazoo, Michigan, that was also referenced in the IOM study. This was a large project, costing over $180 million. It incorporated features such as access to nature, enhanced personal control, positive distractions, and a stress-reducing environment. Metrics included employee turnover, before and after, patient outcomes, length of stay, cost per unit of service, waiting time, patient satisfaction, and organizational behaviors.

Some of the early results are as follows:

- 7 fewer nosocomial infections per 1,000 patients,
- Savings due to fewer patient transfers,
- 1 percent market share increase,
- 80 percent occupancy rate since opening (5 percent increase),
- Nurse turnover rates below 12 percent,
- Increased employee satisfaction, and
- Patient satisfaction 95.2 percent.

Just reducing the nosocomial infection rate saved $300,000 per year. The hospital has done very good environmental surveys that correlate very well across the board, and the staff believe they are providing a much better level of care.

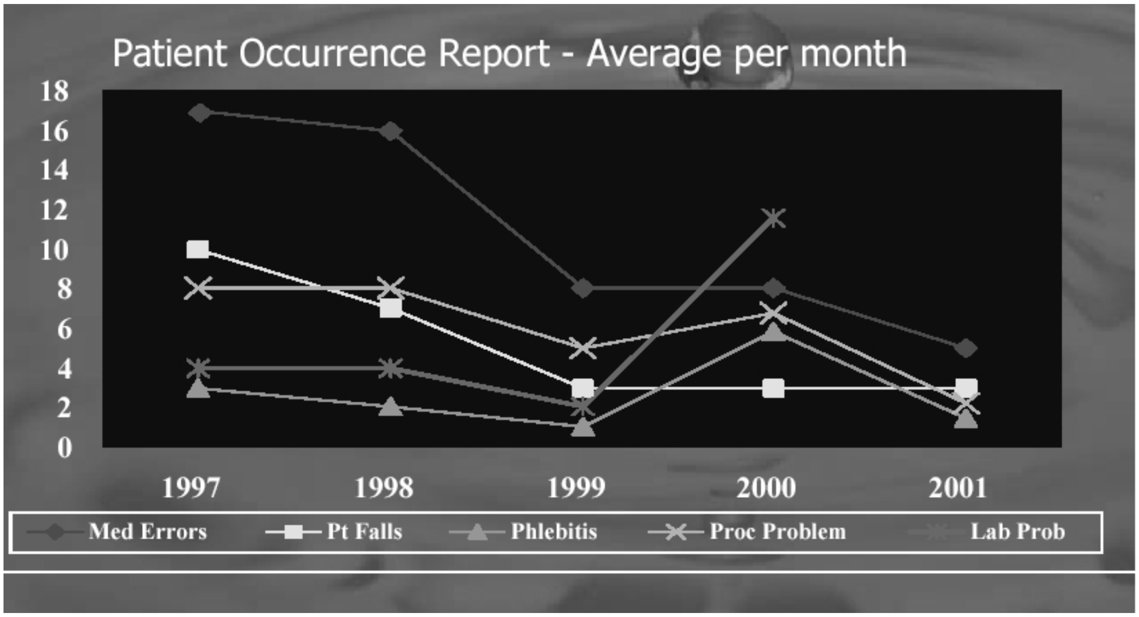


FIGURE 5.4 Selected health data, Clarian Methodist Hospital.

CLARIAN METHODIST HOSPITAL

The next project is Clarian Methodist Hospital in Indianapolis, which is also referred to in the IOM study. This was a small project, a comprehensive cardiac care unit essentially managed and run by a wonderful lady named Ann Hendrick. Clarian wanted to measure clinical outcomes, patient and staff satisfaction levels, education and personal growth, and cost and efficiency improvements.

One immediate result was that patient falls decreased 75 percent. This is important because patient falls are a very serious issue in hospitals. The average cost of a patient fall that is not litigated is about $10,000 for increased length of stay, increased medication, repairing broken bones, and so on. Data also show that patients who fall in hospitals actually die three months earlier than people who do not fall because they are afraid of falling a second time and become more tentative. This changes their lifestyle, they become less active, and their health just seems to spiral downward.

Figure 5.4 is a chart from Clarian that compares the incidence of medical errors, patient falls, phlebitis, lab problems, and process problems after moving into the new facility in 1999. What caused falls to decrease? The hospital built much larger rooms than are typical, so that a visiting family has a place to stay and be with the patient in the room on a routine basis. The presence of additional hands and eyes with the patient was all that was needed. This was a serious if novel approach to the issue of patient falls that produced positive results.

Patient transfers were reduced substantially by, again, going to all single-patient rooms. The quality of communication between the caregiver and the patient improved dramatically when the patient was in a single room. Physicians don’t feel that they have to whisper or talk in riddles because they don’t want someone else to overhear.

Figure 5.5 is the matrix we are using to structure the data collection effort for all 18 pebble projects. Our next step will be to generate more pebbles to see if we can replicate some of these findings.

Why is all this so important? In this country alone, we are currently spending $15 billion a year in capital expenditures for health care facilities, and that is expected to rise to $25 billion by 2010. Now is the time to build a business case for better health care facilities and a logical case for evidence-based design.

Comparative Group → Outcome Researched ↓	Patients (S,G or A)	Employees/ Physicians (S.G or A)	Family/ Visitors (S, G, A)	Community	Organization/ Institution
Clinical/Technical Outcomes		N/A	N/A	N/A	N/A
Economic/Financial Resource Utilization					
Operational Improvements				N/A	
Satisfaction, Quality of Life, Cultural Assessment					
Safety/Error Reduction Outcomes			N/A		N/A
Environmental/ Sustainability					
Other Measurable Outcomes					

FIGURE 5.5 Pebble project research matrix.

I would like to close with the example of what I call Fable Hospital. None of the data is invented, all are based on the early findings of our pebbles. What is hypothetical is that everything occurs in one place at one time.

Fable Hospital is a 240-bed regional open medical center, estimated to cost $240 million or $1 million per bed, which is about right. Our best work results when our clients provide value-driven leadership. Therefore, high values for quality, safety, patients, family, and staff, attention to cost, and community responsibility are assumed.

Fable Hospital would be a place of tranquility. Our design innovations included large oversized windows to provide lots of natural light in single rooms set up for variable-acuity patients. Variable acuity means that the patient can be admitted to one room and, for the most part, stay in that room under varying health conditions before being discharged. The benefit of variable-acuity rooming is related to the fact that the error rate increases 75 percent every time a patient is moved: Sometimes the data stay with the patient but oftentimes they do not.

Fable Hospital would have decentralized, barrier-free nursing stations. With such stations the nurses are closer to the patients, which results in fewer patient falls because the nurse is with the patient instead of running around finding supplies and other things. Video evidence from Clarian Methodist showed that in a 12-hour shift the nurses were actually with each patient for 20 minutes. The rest of the time they are fetching and carrying and running around and reporting and writing and on the telephone and so on. They generally are not providing patient care. That is one of the reasons we found such low satisfaction rates for nurses. They are not doing what they joined the profession to do.

Art, music, and gardens are receiving additional attention. A children’s hospital we are working on in Chicago has a poet in residence to spend time in the hospital, writing poetry, working on poetry with the children, and posting the “poem of the day” on a number of bulletin boards around the hospital. Additional consultation spaces are provided so that patients can have direct access to the caregivers and receive information so that they know what to do, as can the family members.

The estimated cost of all the added design features is $12 million, or 5 percent of the total project cost. The expected benefits of that additional expenditure are shown in Table 5.1. There is an estimated first-year cost

TABLE 5.1 Fable Hospital: First Year Financial Impacts of Design Features.

Design Feature Impacts	Financial Impacts
80% reduction in falls	$2,452,800 in savings
80% reduction in transfers	$3,893,200 in savings
Decrease in nosocomial infections	$80,640 in savings
Reduction in nursing staff turnover	$164,000 in savings
16.4% decline in use of pain medication	$1,216,666 in savings
1.5% market share increase	$2,168,100 increase in revenue
Increase in philanthropy	$1,500,000 increase in revenue
Total	$11,475,406 in savings and increased revenue

savings of $7.8 million. On the revenue side, based on actual experience with real hospitals, we conservatively estimated almost $3.7 million from increased market share and philanthropy. The total of savings and increased revenue in the first year alone ($11.5 million) essentially covers the cost of a vastly superior design.

All of the savings described are drawn from the Center for Health Design's pebble projects (http://www.healthdesign.org). No one has yet achieved this level of improvement, but we are all trying. I would like to be the first to design a real Fable Hospital.

The moral of this fable is that illness is expensive, but well-being pays dividends. Investment in better buildings pays off directly and indirectly, and we are getting close to being able to prove that. We must. Our resources are finite, and our health care system is terribly inefficient. We have to maximize value, and I am committed to using evidence-based design instead of the status quo.

ABOUT THE PRESENTER

Derek Parker is chairman of Anshen+Allen Architects and president of a renewable energy company, Medergy. He has more than 40 years of experience focused on the planning and design of health care and academic research facilities. Mr. Parker has made significant contributions to health care and university architecture in the United States, as well as nine technologically and culturally diverse nations including the United Kingdom, Australia, Canada, the Peoples Republic of China, the former Soviet Union, Turkey, Japan, Italy, and the Philippines. He is a Fellow of the American Institute of Architects, a member of the Royal Institute of British Architects, and numerous architecture and design review boards. Mr. Parker also serves as an adjunct professor at the University of Hawaii and as a board member of the Center for Health Design.

6

Implementing Health-Protective Features in Buildings: Practical Actions—Case Studies

E. Sarah Slaughter

MOCA Systems (Management of Construction Activities) uses proprietary technology to rapidly produce fully integrated project cost estimates and construction schedules. The heart of the MOCA technology is its *MOCABuild*^{TM} software, a dynamic microsimulation system that models the performance of work on a construction site, literally building the facility in the computer before it has to be built on-site. The system's database incorporates specific construction activities derived from about 65,000 hours of time and motion studies on construction projects; the activities of every worker on each physical component have been identified and tied to the resources and time required to perform them (see Figure 6.1).

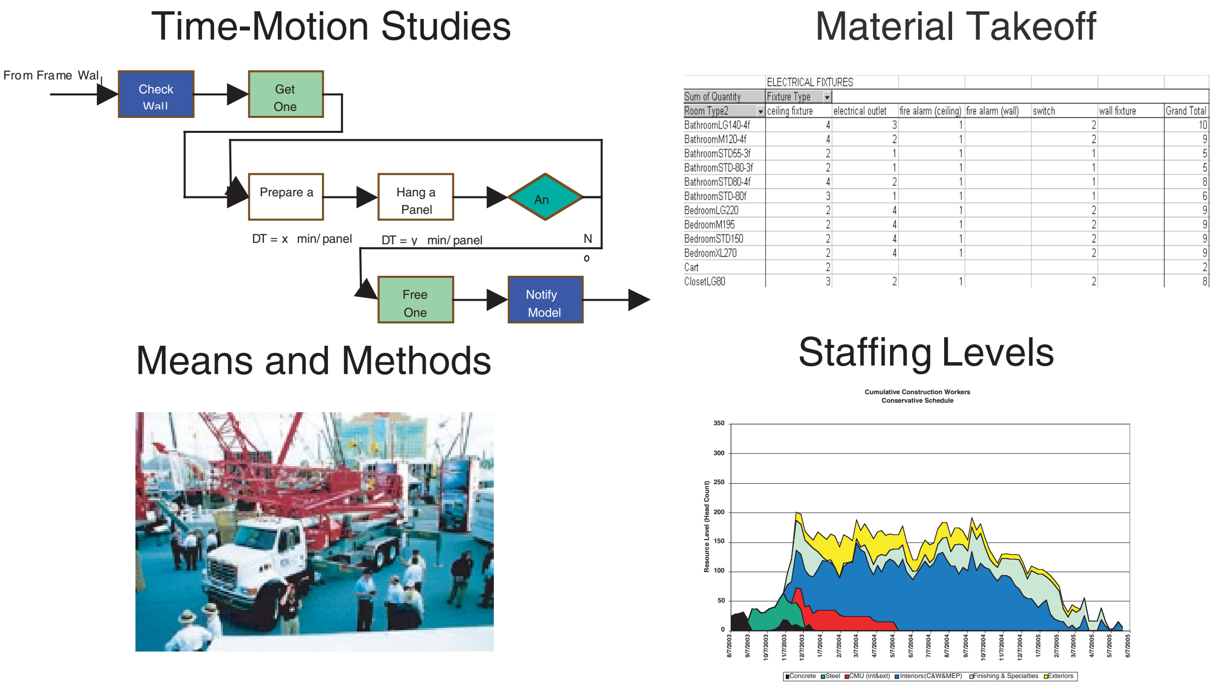
As a result, an owner, architect, or general contractor can weigh design and construction options, benchmark performance expectations, and identify and correct problems that otherwise would remain undiscovered. MOCA provides the data needed by management to make decisions that are both correct and timely: cost estimates, material quantities, construction durations, and detailed construction schedules and staffing requirements for each subcontract. It typically takes about one hour to run a simulation for these construction projects, and several simulations can run simultaneously, producing results for multiple scenarios to the owner and its project team overnight.

One significant problem that has surfaced in working with clients over the past four years, particularly in terms of implementing new systems and practices, is uncertainty. In particular, how much is it actually going to cost to include certain elements, including those that might be health protective? How can the information just learned be used in the next project? MOCA has proved to be very effective in reducing that uncertainty to acceptable levels.

This presentation focuses on five case studies that illustrate how MOCA was used to analyze the impacts on costs and time of changes to specific projects that incorporate health-protective design elements. The elements include interior partitions, exterior enclosures, service systems, and the structure in four building types: federal courthouse and office building, a large high school, office buildings, and a high-rise residential building.

FEDERAL COURTHOUSE AND OFFICE BUILDING

Following the bombing of the Alfred P. Murrah Federal Building in Oklahoma City in 1995, a number of approaches were developed to increase the safety of the occupants of buildings in the event of future attacks. One of the suggestions that emerged to significantly diminish harm from projectiles in either a natural or man-made



	ELECTRICAL FIXTURES						
Sum of Quantity	Fixture Type						
Room Type2	ceiling fixture	electrical outlet	fire alarm (ceiling)	fire alarm (wall)	switch	wall fixture	Grand Total
BathroomLG140-4f	4	3	1		2		10
BathroomM120-4f	4	2	1		2		9
BathroomSTD55-3f	2	1	1		1		5
BathroomSTD-80-3f	2	1	1		1		5
BathroomSTD80-4f	4	2	1		1		8
BathroomSTD-80f	3	1	1		1		6
BedroomLG220	2	4	1		2		9
BedroomM195	2	4	1		2		9
BedroomSTD150	2	4	1		2		9
BedroomXL270	2	4	1		2		9
Cart	2						2
ClosetLG80	3	2	1		2		8

FIGURE 6.1 Elements of the *MOCA Build*™ software.

disaster was to use a double layer of sheet rock on each side of interior partitions. In addition to increased safety from projectiles, improved sound attenuation is provided.

We studied the effects of building a new courthouse and office building with a double layer of sheet rock and found that the estimated cost increase was less than 1 percent for both labor and materials with essentially no impact on schedule.

RENOVATION AND ADDITION TO AN EXISTING HIGH SCHOOL

The next example is a major renovation and addition to a high school that would be occupied during construction. The renovation was to proceed in sections, and the designer has specified concrete masonry units (CMUs) for the interior partitions. This is not unusual since many existing schools have CMU block, but this material also tends to increase noise and echoing, particularly in hallways. The alternative was to substitute interior drywall partitions for the CMUs to attenuate sound.

Two other findings emerged from this project. First, when compared to drywall, CMUs are problematic for phased construction projects where design changes are inevitable. If a change is required, the CMUs have to be taken out with a jackhammer. The drywall is much easier to remove, and its removal entails less dust and noise. Also, in Massachusetts, where skilled labor is very expensive, eliminating CMU partitions (and the cost of masons) for this specific project had a tremendous impact on reducing costs—32 percent for the interior walls subcontract, 4 percent for related electrical work, and 2 percent for the overall project cost. This was accomplished with no overall impact on the project schedule. An additional benefit of saving this much on a public project (where all funding will be spent) was that these funds could then be available for other desirable building features, potentially including health-protective features that might not otherwise be incorporated.

- Cost Increase
  - <1% for Shades
  - <1% for Electrical
  - <<1% for Whole Project
- Construction Duration Increase
  - <1% for Shades, Electrical
  - <<1% for Project

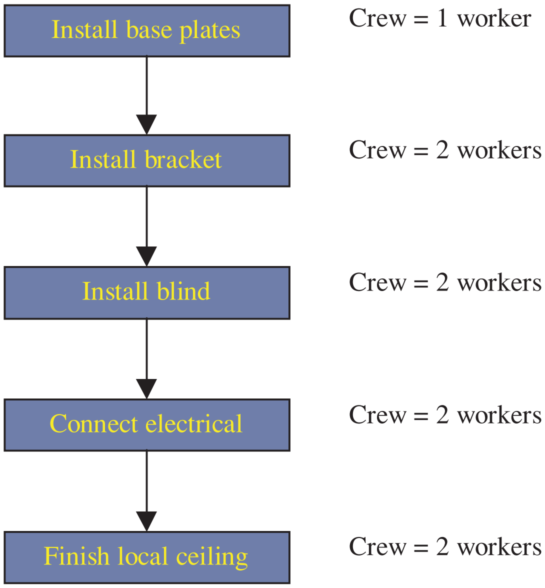


FIGURE 6.2 Impacts of installing active shade mechanisms.

CORPORATE HEADQUARTERS

The owners of this building wanted to obtain a platinum rating under the LEED™ (Leadership in Energy and Environmental Design) rating system of the U.S. Green Building Council. This project incorporated active shade mechanisms on all windows to track the movements of the sun and adjust window shades accordingly. This system decreases glare and increases the level of natural light that is reflected into the building while reducing the heat gain from the windows. However, oftentimes when new technologies are proposed with which the contractors are not familiar, rather arbitrary premiums are placed on their installation in the specialty contractor bid. The owners were incorporating so many new features in this project that they could not afford to pay a premium for every element, so the task was to help them realize their goal of incorporating sustainability technologies while decreasing the perception of risk to the subcontractors, the contractors, and even the financing institution.

A very simple flow diagram was developed that showed how tasks were to be performed, and a simulation was run showing the flow of work in the work zones on one floor and the flow from floor to floor. The specialty contractor and superintendent were then able to visualize the feasibility of the installation and buy into the process. The cost and schedule impact was less than 1 percent for the shades and related electrical work and much less than 1 percent for the building overall (see Figure 6.2).

OFFICE BUILDING

In a related activity, the feasibility of designing for a 100-year facility life was analyzed. The question was basically: "How do you design a building to accommodate all the changes that will be necessary over the span of a century?" One of the recurring issues in major renovations is what to do with the fire protection system when the interior partitions are moved. The typical approach is to shut down and drain the system, cut the pipe, move the partitions, and then reverse the process. Needless to say, this is a costly process that greatly increases the facility's downtime.

There is a fully tested and rated system available that consists of a flexible hose that goes from the main branch element to the fire protection sprinkler head, so contractors can move it without having to turn off the system. One model uses gaskets that integrate into the ceiling grid and is particularly appropriate for surgery suites, clean rooms, and other areas where the penetrations between the plenum ceiling area and the room underneath must be minimal.

In this project the installation time for the fire protection system was reduced by 27 percent, and the total cost of the project was reduced by 2 percent. However, the real savings was that, when combined with other activities, the total time required for alterations decreased by over 10 percent. That means that other projects could potentially be completed one to four months sooner, which can be a significant benefit for many clients. A system such as this could not only be beneficial to the health and safety of occupants but could also have positive economic benefits for the owner.

RESIDENTIAL HIGH-RISE

This project in Puerto Rico needed to account for both seismic and hurricane loads and utilized a special steel frame with full moment beam-to-column welded connections. The option examined employed a column tree, which consists of beams stubs prewelded to the column, and in the field the beam is bolted to the beam stub. This reduces the need for welding on-site, produces higher-quality welds, and significantly reduces the exposure of workers to hazardous on-site welding conditions. In this case, the chosen assembly decreased the cost of the steel by 5 percent and reduced the amount of iron worker labor on-site by 50 percent (see Figure 6.3). Construction time was decreased by 13 percent for the steel erection and by 8 percent for the overall project.

However, this option can have significantly different impacts on steel erection cost and duration for other structural configurations. A similar analysis of steel column trees in Boston showed an increase in cost of approximately 1 percent, which indicates that the potential savings from prefabrication of these elements are very site and resource specific.

- Cost Decrease
  - — ~5% for Steel
- -50 % for IW Labor Cost
- +20% for Fabrication
  - — ~1% for Project
- Construction Duration Decrease
  - — 13% for Steel Erection
  - — 8% for Project

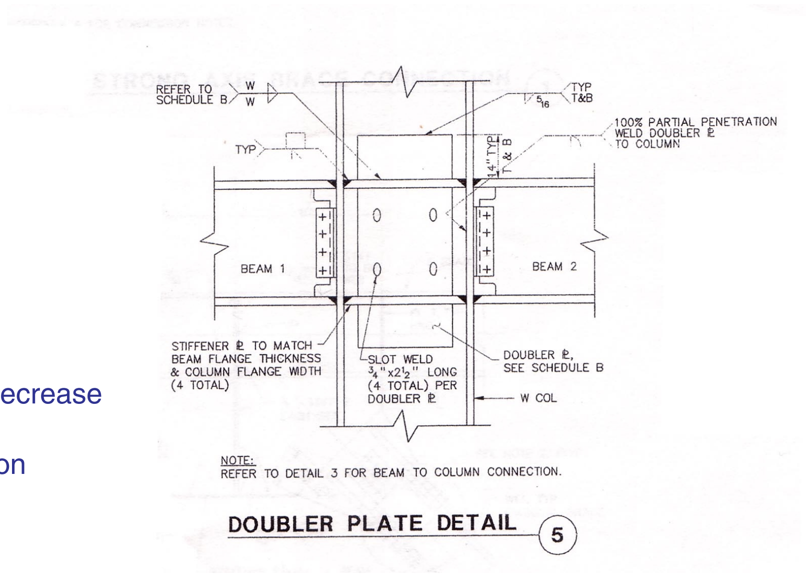


FIGURE 6.3 Impacts of alternative steel frame assembly.

BUILDING PROGRAM APPROACHES FOR IMPLEMENTING HEALTH-PROTECTIVE FEATURES

There are several proven approaches for incorporating desirable features across a wide range of buildings quickly and effectively that could readily apply to many of the health-protective features discussed at the workshop. The first is the *platform design approach*, which uses a standard building core and shell that are adapted with certain features such as the air ventilation system, operable windows, or other key elements. Hotels, office buildings, and other production developers frequently make use of this system. It separates the performance and the design from the different elements and is similar to the way that cars are now designed.

In contrast, the *engineering systems approach* is much more effective when dealing with complex, technology-sensitive, high-performance buildings, such as research and development facilities, laboratories, and so forth. In these cases, there are families of systems where the interdependencies between the elements are absolutely critical. They often require very advanced performance simulation in such areas as airflow, electrical load, and myriad other factors.

The third approach is the *building library*, which works well for hospitals and universities that have campuses composed of a variety of building types some of which may be brand-new while others are hundreds of years old. Despite great differences in the building shell, these facilities often have a standard room type (e.g., classroom or surgical suite), and clients want to know the cost to incorporate certain common elements or features into their existing facilities. These room definitions can be stored in a system library for easy reference as future needs arise.

ORGANIZATIONAL LEARNING

If decision makers in both the public and the private sectors are to be convinced that they should incorporate health-protective features in buildings, they must understand what it is they are being asked to do. A clear detailed definition of each alternative must be provided. Clear criteria to distinguish the differences among these alternatives before making a selection are required. Methods for calculating the impact of a specific element or project and for measuring and monitoring its effectiveness should be in place. Finally, there should be an established method or procedures for comparing and disseminating the results of various projects.

ABOUT THE PRESENTER

E. Sarah Slaughter, Ph.D. is the president and chief executive officer of MOCA Systems, Inc., as well as the developer of MOCA's core technology. Before founding MOCA in 1999, she was a professor in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT) specializing in Construction Management. She has researched innovations in design and construction for 15 years and has published more than 50 articles and books on this topic. Dr. Slaughter is a recognized leader in her field, and has been selected for several prominent committees and awards. She received all of her degrees from MIT, including a B.S. in Civil Engineering, an M.S. in Civil Engineering and Technology and Policy, and a Ph.D. in Civil Engineering and Management Science.

Appendixes

A

Workshop Agenda

WORKSHOP ON IMPLEMENTING HEALTH-PROTECTIVE FEATURES AND PRACTICES IN BUILDINGS

The Lecture Room
National Academy of Sciences
2100 C Street, NW
Washington, DC

November 17-18, 2003

Monday, November 17, 2003

8:30 a.m.	**Sign-in and Continental Breakfast**
9:00 a.m.	**Welcoming Remarks and Workshop Objectives** Richard Little, Board on Infrastructure and the Constructed Environment
9:15 a.m.	**Overview of the Knowledge Base. Formal Presentations.** Jim Woods, Building Diagnostics Research Institute Mark Mendell, Lawrence Berkeley National Laboratory Mark Rea, Lighting Research Center, Renssalear Polytechnic Institute
10:30 a.m.	**Break**
11:00 a.m.	**Group Discussion—Facilitated by Dr. Craig Zimring, Georgia Institute of Technology** What Do We Know About How Building Design and Operations Effect The Health of Indoor Workers and Occupants? What Don't We Know?

12:00 p.m.	**Lunch**
1:00 p.m.	**Practical Actions That Can Be Taken to Improve Indoor Environmental Design. Formal Presentations.** Derek Parker, Anshen+Allen Architects Sarah Slaughter, MOCA Systems, Inc.
2:00 p.m.	**Charge to Break out Sessions:** 1. Identify institutional, behavioral, and other barriers to implementing building features and practices that have been shown to improve indoor environmental quality and the health of indoor workers and occupants. 2. Identify methods, strategies, and practices that could be used to overcome these barriers.
2:15 p.m.	**Breakout Groups** **Group Leaders:** Dennis Dunne, California Department of General Services—Room 150 Derek Parker, Anshen+Allen Architects—Room 180 Craig Zimring, Georgia Institute of Technology—Lecture Room
4:30 p.m.	**Groups Reassemble in Lecture Room** Demonstration of Research Database—Satish Kumar, Lawrence Berkeley National Laboratory
5:00 p.m.	**Reception—Great Hall**
6:00 p.m.	**Dinner—Great Hall** Movie: *Beyond Intuition*

Tuesday, November 18, 2003

8:30 a.m.	**Continental Breakfast**
9:00 a.m.	**Reports from Breakout Groups** Dennis Dunne Derek Parker Craig Zimring
10:00 a.m.	**Group Discussion: What Practical Actions Can Be Taken By Those in the Building, Health Care, and Other Industries to Create More Healthful Indoor Environments?**
11:30 a.m.	**Summary and Next Steps** Richard Little
12:00 p.m.	**Adjourn**

B

Workshop Participants

Nicholas Ashford, Ph.D.
Professor of Technology and Policy
Massachusetts Institute of Technology

Charlene Bayer, Ph.D.
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Materials & Chemical Sciences Division
Georgia Tech Research Institute

Tobie Bernstein, J.D.
Senior Attorney
Environmental Law Institute

Roger Bezdek
Economist
Management Information Services, Inc.

Charles Blumberg, FIIDA
Architect and Interior Designer
National Institutes of Health

William Brodt, P.E.
Experimental Facilities Engineer
NASA Facilities Engineering Division

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Adjunct Senior Lecturer on Environmental Microbiology
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Harvard Public School of Health

Rosalyn Cama, FASID
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Cama, Inc.

Leon Chatelain
President
Chatelain Architects

Kimberly Cullinane
Green Schools & Green Buildings Initiatives
Massachusetts Technology Collaborative

Dennis Dunne
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California Department of General Services

Eric Emblem
Executive Director
National Energy Management Institute

Helen English
Executive Director
Sustainable Building Industries Council

Paul Fisette
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Building Materials & Wood Technology
University of Massachusetts

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Staff Scientist & Group Leader
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Lawrence Berkeley National Laboratory

Russell Gentry, Ph.D., P.E.
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Georgia Tech College of Architecture

Paul Gilbert, P.E., NAE
Senior Vice President
Parsons, Brinckerhoff, Quade & Douglas

John Girman
Chemist
Environmental Protection Agency

Steven Glazner
Director of Knowledge Management
Association of Higher Education Facilities Officers

Harry Goradia
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Elizabeth Grosh, CSP, ARM
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Prudential Insurance Company

Vijay Gupta, P.E.
Mechanical Engineer/HVAC
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David Harris, FAIA
President
National Institute of Building Sciences

Lt. General Henry J. Hatch, USACE (ret.)
Chair, Federal Facilities Council

Judith Heerwagen, Ph.D.
Environmental Psychologist
J.H. Heerwagen and Associates

John Herzog
Vice President, Public Policy
Air Conditioning Contractors of America

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Office of Facilities Management
Department of Veteran Affairs

Andy Keirn
Office of Facilities Management
Department of Veterans Affairs

Meg Klekner
Sr. Facilities Officer
Environmental Health and Safety
International Monetary Fund

Kurt Knight
Office of Facilities Management
Department of Veterans Affairs

Brian Kong
Mechanical Engineer
National Institutes of Health

Satish Kumar, Ph.D.
Environmental Energy Technologies
Lawrence Berkeley National Laboratory

Chi Leng
Office of Applied Economics
National Institute of Standards and Technology

Hal Levin
Architect-Engineer/Scientist
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Mark Mendell, Ph.D.
Epidemiologist
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Johns Hopkins Bloomberg School of Public Health

Derek Parker, FAIA, RIBA
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Mark Rea, Ph.D.
Professor of Cognitive Science
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