AIR QUALITY SCIENCES

Energy Conservation and Indoor Air Quality:

Partnering to Protect Public Health

Air Quality Sciences, Inc.

1337 Capital Circle

Marietta, GA 30067

(770) 933-0638

www.aqs.com

Partnering Required to Protect Public Health

In response to concerns about global warming and the growing popularity of sustainable (green) building in both the commercial and residential sectors, energy conservation usually takes center stage. Maintaining good indoor environmental quality (IEQ) is included in most green building protocols, such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED) Green Building Rating System™, but it is not emphasized in news media reports and other marketing communications materials touting the benefits of "green." The focus instead is on how to reduce carbon emissions and protect the outdoor environment. While protection our natural resources is vital to sustaining our environment, protecting human health by providing clean, non-toxic air is critical. This applies not only to outdoor air, but also to the air within our homes, office buildings, schools and healthcare facilities, where people spend more than 90 percent of their time.

With the epidemic rates of asthma and respiratory disease and an alarming increase in autism, learning disabilities and other neurological diseases among children, the indoor air that we breathe is of vital importance. To pursue energy conservation in homes and buildings without taking the quality of indoor air into consideration puts building occupants at unnecessary health risk. Conversely, to pursue good indoor air quality (IAQ) without considering the efficient use of energy may unnecessarily increase energy costs and emissions of greenhouse gases, thereby contributing to outdoor air pollution and possibly even global warming. The two must go together.

From a public health perspective, interest in IAQ has waxed and waned over time, but received new attention when the OAPEC Oil Embargos and subsequent energy crises in the 1970s changed how buildings are designed, built and operated. Consequently, the relationship between IAQ and energy has become even more important. Results of numerous studies since then have demonstrated that the design of the building and its heating, ventilating and air-conditioning (HVAC) system, materials used to construct a building's exterior and interior, construction practices, operating and maintenance, and human activities have a direct influence on energy use, carbon and particulate emissions, and IAQ.

Yet as demand for energy continues to increase and concerns about global warming grow, an important lesson on IAQ is at risk of being forgotten: IAQ and energy conservation are interdependent and both should be given the same priority to ensure the health of building occupants.

This report briefly reviews the history of IAQ and energy conservation during the past 40 years and how indoor air contaminants can affect human health. For a review of the history of IAQ and energy conservation before 1970, see the companion AQS Research Report, *Energy Conservation and Indoor Air Quality: Lessons From the Past Have Relevance for the Future*, which is available free from the AQS Aerias IAQ Resource Center (www.aerias.org). The reports also highlight studies that demonstrate the benefits of good IAQ and that IAQ and energy are complementary not competing goals. Gaining this perspective and understanding will serve as a reminder that outdoor and indoor environments are not mutually exclusive nor are the efficient use of energy and IAQ.

OAPEC Oil Embargos, Energy Conservation: Tighter Buildings, Poor IAQ

Beginning the 1960s and early 1970s, there was a great deal of interest in cleaning up the outdoor environment. The United States Congress passed the US Clean Air Act in 1963, the Air Quality Act in 1967, the Clean Air Act Extension of 1970, and Clean Air Act Amendments in 1977 and 1990. The US Environmental Protection Agency (US EPA) was created in 1970. Its initial mission was to repair the damage already done to the natural environment and to establish new criteria to guide people in the US to make a cleaner environment a reality. The US EPA's work on indoor air quality did not begin until the 1980s.

With respect to energy conservation, until the early 1970's, there was a popular belief that the cost of energy was decreasing. As a result, efficiency ceased to be a major concern. The US received a startling wake-up call during the 1973 and 1974 OAPEC Oil Embargos and the resulting energy crises, when energy prices in the US rose dramatically and Americans experienced energy shortages (Wulfinghoff 2000).

Seemingly overnight, the prevailing view shifted from the energy supply keeping ahead of demand to the energy supply lagging behind demand, especially when considering the future availability of fossil fuels. Energy efficiency and energy conservation became buzzwords of the 1970s, prompting a dramatic rethinking of how to design, build and operate buildings (Wulfinghoff 2000). Table 1 lists key differences in the understanding of energy conservation between the pre- and post-1973 energy crisis.

Table. 1. Differences in the Understanding of Energy Conservation: Pre- and Post-1973*

Pre-1973 Energy Crisis	Post-1973 Energy Crisis
Energy sources are discovered ahead of demand.	Energy sources are being depleted, without replacement.
An issue for individual parties.	A societal issue.
A technical aspect of individual machines and processes.	A freestanding issue, struggling to become technically integrated.
Perceived as an issue of labor requirements and fuel costs, to be addressed by technical and economic means.	Perceived mainly as a resource conservation and/or outdoor environmental issue. Distinct interest groups variously seek to address it by economic, technical, political, social, and/or metaphysical means.

* From Wulfinghoff 2000.

To help conserve energy, Americans were encouraged to turn off lights in rooms that were unoccupied and turn down their thermostats in winter and up in summer. In commercial buildings, resetting the temperature had little effect on energy consumption as the HVAC systems used in these buildings were designed to heat and cool simultaneously to maintain constant temperatures and relative humidity. As a result, HVAC systems were turned off altogether, using a variety of schemes such as peak demand scheduling, duty cycling, economizer operation, night shutdown and occupancy-determined start up. A greater dependence on recirculated air also emerged to minimize the cost of conditioning and distributing outside air (Addington 2000). Another strategy was to construct tighter buildings and homes to minimize the amount of outdoor air infiltrating from outside, thus reducing energy costs.

Just before the 1973 oil embargo, the American Society of Heating and Ventilating Engineers (ASHRAE) proposed the first major change to ventilation standards in the US for the first time in almost 100 years, with the publication of *ASHRAE Standard 62-73 for Natural and Mechanical Ventilation*. Interestingly, the goal was not energy conservation or good IAQ, but "to give HVAC system designers more latitude in specifying equipment." Over the past 30 years, ASHRAE has continued to revise this standard to address indoor environmental concerns, but its revisions have been complicated by "the inherent conflict between energy conservation, which minimizes ventilation, and the need to maintain acceptable indoor air quality, which maximizes ventilation" (Addington 2000). The current versions are ANSI/ASHRAE 62.1-2007, *Ventilation for Acceptable Indoor Air Quality*, and ANSI/ASHRAE 62.2-2007, *Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. The energy crisis also inspired ASHRAE to write an energy conservation standard, known today as ANSI/ASHRAE/IESNA 90.1-2004,*Energy Standard for Buildings, Except Low-Rise Residential Buildings*, and ANSI/ASHRAE 90.2-2007, *Energy Efficient Design of Low-Rise Residential Buildings*. For more information on these standards, visit the ASHRAE website at www.ashrae.org.

New ways of managing ventilation developed in response to changes in ventilation standards. The major change was from constant air volume (CAV), which "maintains ideal and continuous environmental conditions throughout the building by utilizing the thermal inertia of large volumes of air", to variable air volume (VAV), which keeps the temperature of the "air stream relatively constant, but the amount of airflow is varied, with room or zone thermostats determining how much is to be delivered." Sophisticated, intelligent energy management systems (EMS) also have evolved to manage the requirements of energy conservation and IAQ standards (Addington 2000).

The energy conservation strategies of the 1970s had an unintended adverse impact, however, on the health of building occupants and eventually spawned an epidemic of indoor mold growth, which peaked just after the turn of the millennium. Confounding these problems was a shift from natural to synthetic materials used to construct, finish and furnish building interiors, leading to significant off gassing of volatile organic compounds (VOCs), including formaldehyde, which became a major problem for office buildings, schools, and all buildings with mechanical ventilation. In addition, electronic office equipment became a mainstay beginning in the 1970s. While electronic office equipment greatly improved worker efficiency and productivity, some copiers and computer printers generate particulates, which can adversely impact on health.

Among the symptoms reported were headache, eye irritation, nose and throat irritation, and general fatigue to name a few examples. Results from a study of office workers in 56 randomly selected buildings quantified the extent of the problem, by finding that about 23 percent of office workers surveyed reported two or more frequent sick building syndrome (SBS) symptoms that improved when they were away from the workplace (Brightman et al 1998). For the sake of argument, when applying this percentage to all US office workers and teachers (64 million as of 1997), an estimated 15 million people experience at least two SBS (Fisk 2000). While this is a hypothetical number, it does demonstrate the potential widespread impact of poor IAQ.

In addition to SBS, the prevalence of allergies and asthma has exploded in the past 30 years. Specifically, from 1980 to 1994, the proportion of Americans with asthma increased by 75 percent. In children under the age of five, the proportion grew by 160 percent. Today, 20 million people in the US have asthma, 9 million of which were children, and 10 million people have allergic asthma (AAAAI 2005). Much of this increase is attributable to poor IAQ.

Mold, VOCs, Climate Change, Green Building Spurs Rethinking of Buildings

The 1990s began with a short-lived energy crises brought on by the invasion of Kuwait and the Gulf War, along with the collapse of California's competitive electricity markets and the threat of electricity shortages in the Western US. The mid-1990s saw inexpensive and plentiful energy supplies, and consequently, the federal government's energy policy became somewhat complacent. The focus was more on the environmental impacts of energy consumption and production, including impacts of greenhouse gas emissions and climate change. By the end of the decade, however, tight supplies and growing demand led to rising prices for oil, natural gas, and wholesale electricity, and significant energy price volatility (Joskow 2001). As a result, energy conservation once again became paramount and in recent years, along with other environmental concerns, has given a sizable boost to fledgling green building initiatives.

The 1990s also was a decade during which scientists really began to understand the nuances of poor indoor air quality and its impact on human health, comfort and productivity. One of the most authoritative and quoted studies to date on quantifying potential health and productivity benefits from providing good indoor environmental conditions (IAQ, thermal and lighting) was conducted at Lawrence Berkeley National Laboratory by Bill Fisk and his colleagues. Their findings reflect an analysis of a large number of earlier studies (see Table 2 for a summary of their findings).

Fisk et al concluded, "Improving air quality would not only lead to significant reductions in illness but would have a direct positive impact on worker productivity…The potential direct increase in office workers' performance was estimated to range between 0.5 percent and 5 percent" (Fisk 2000, Fisk and Rosenfeld 1997, Kumar and Fisk 2002).

Table 2. Potential Annual Healthcare Savings and Productivity Gains From Improving Indoor Environments*

Source of Productivity Gain	**Potential Annual Health Benefits in US**	**Potential US Annual Savings on Productivity Gain (1996 $US)**
Reduced respiratory disease	16 to 37 million avoided illnesses	$6 to $14 billion $23 to $54 per person
Reduced allergies and asthma	8% to 25% decrease in symptoms in 53 million people with allergies and 16 million people with asthma	$1 to $4 billion $20 to $80 per person (with allergies)
Reduced sick building syndrome symptoms	20% to 50% reduction in symptoms experienced frequently by 15 million workers	$10 to $30 billion ~ $300 per office worker
Improved worker performance from changes in thermal environment and lighting	Not applicable	$20 to $160 billion

* William Fisk, “Health and Productivity Gains from Better Indoor Environments” Fisk 2000 ** Reported in 1997 US dollars.

Towards the end of the 1990s and into the new millennium, fears about indoor mold growth sparked an epidemic of lawsuits, centered on potential ill effects of being exposed to mold. One of the root causes of the indoor mold growth, in many cases, is building envelopes and wall systems that do not allow for the free flow of air, a byproduct of poorly designed and maintained HVAC systems and tighter buildings. Construction defects that allow liquid water and moisture to infiltrate roof and wall systems also are a factor. Moist air from the outside becomes trapped and condenses on the cool side of the wall, providing ideal conditions for mold to grow. This problem is particularly prevalent in hot and humid climates, but no building in any climate is immune. Local, state and federal governments authorized studies in attempts to address the problem, particularly as public buildings, such as courthouses and schools, seemed particularly vulnerable. After insurance companies declined to cover mold, the number of lawsuits declined and interest has decreased. Regardless, moisture management is still an important part of building design, operation and maintenance, as researchers have established damp buildings as a risk factor for people with allergies and asthma (see the AQS Research Report, *Asthma and Damp Buildings: Making the Connection*, for more information about these studies).

But what has really spurred the most recent change in building design, construction, operation and maintenance is the conservation of energy and natural resources, as a way to address global climate change. According to the US Green Building Council, US buildings account for:

- 36 percent of total energy use
- 65 percent of electricity consumption
- 30 percent of greenhouse gas emissions
- 30 percent of raw materials use
- 30 percent of waste output
- 12 percent of potable water consumption

The commercial and residential building sectors account for 38 percent of US carbon dioxide emissions per year, more than any other sector. Buildings in the US alone emit more carbon dioxide each year than those of any other country except China. Most of these emissions come from the combustion of fossil fuels to provide heating, cooling and lighting, and to power appliances and electrical equipment. The goal of organizations, such as the USGBC, is to transform the built environment to be more energy-efficient and climate-friendly, thereby reducing the threat of climate change (USGBC 2007).

The green building trend is catching on, and the numbers tell the story. As of August 2007, there are more than 7,000 commercial and more than 7,000 residential registered projects worldwide (all 50 US states and 41 countries). Industry data further demonstrates how green building has become a market force. The USGBC reports that in 2003 the annual market for green building in products and services was $5.8 billion, a 34 percent growth over 2002 (USGBC Green Building Fact Sheet).

Jerry Yudelson, PE, chair of the steering committee for the 2004 and 2005 USGBC Greenbuild Conferences, predicts that the total number of LEED-registered projects will grow from about 1,760 at the end of 2004 to nearly 10,000 at the end of 2009 (November 29, 2004 press release). He also notes there is a strong interest among developers in incorporating green building goals into their projects, even among those who have no plans to officially register their projects with LEED. He estimates at the end of 2004, the number of these projects was as much as two to three times that of LEED projects, leading him to project that green buildings have penetrated 5 percent of private-sector and 15 percent or more of public-sector projects (Yudelson, EDC-Structure 2005).

For more information about the sustainable (green) buildings trend, see *IAQ vs. Energy Conservation: Competitive or Complementary Goals*, below.

Understanding the Nature of IAQ

The understanding of indoor air has come a long way since the work of Robert Boyle, Wilhelm Scheel and Antoine-Lourent Lavosier (late 18th century) determined that air was a chemical mixture rather than single element and quantified the association between oxygen consumption in human metabolism and carbon dioxide release. As a result of their work, carbon dioxide became a key marker for poor IAQ (Addington 2000).

Research during the past 30 years has determined that indoor air is an intriguing, complex environment that contains a myriad of visible and invisible contaminants, some of which can lead to health problems, lower worker productivity and result in building occupant complaints. These contaminants generally fall in one of two categories: particulates or gases, vapors and odors. The following provides a brief description of each category. For more detailed information, please refer to the following AQS Research Reports, which are available free from the AQS Aerias IAQ Resource Center, Premium Content tab (www.aerias.org):

- Clearing the Air on Indoor Air Cleaners / Purifiers
- Cleaning Products and Processes: Partnering for Healthier Indoor Environments
- If You Build It Green, They Will Come
- Reviewing and Refocusing on IAQ in Schools

Particulates. Particulates are particles that are small enough to suspend in the air. Suspended inorganic particles, such as dust, pollen, fibers or smoke to name a few examples, are often referred to as *aerosols*. Suspended organic compounds and small living organisms, such as bacteria and viruses; mold spores and pieces of a mold colony; dust mites feces and body fragments; cockroach body parts; and dander from cats, dogs and other mammals, are called *bioaerosols* (McDonald and Ouyang 2000).

Particle size is measured in terms of its aerodynamic properties and is expressed as microns (µm) in diameter. Particles can range in size from very small (0.001 µm to 10 µm), which can remain in the air for a long time, up to relatively large (100 µm), which quickly settle out of calm air.

Inhaling particulates can cause eye, nose and throat irritation and increase the risk for respiratory infections. Health care professionals are especially concerned about the long-term effects of inhaling fine particles (less than 2.5 μm), because they can travel deep into the lungs where they can remain embedded for years or be absorbed into the bloodstream. Asbestos and various substances in environmental tobacco smoke (ETS) are well-known examples and some are recognized carcinogens. Exposure to high levels of fine particles also can play a role in developing respiratory diseases such as asthma, bronchitis, pneumonia and emphysema. Larger particles (greater than 10 μm) do not cause as much concern, because they get caught in the nose and throat and are cleared from the respiratory tract by coughing or swallowing (ALA Special Report on Air Cleaners).

Gases, Vapors and Odors. The types of gases or vapors most often found in indoor environments include combustion byproducts, such as carbon monoxide, nitrogen oxides, sulfur dioxide, soot particles and polycyclic aromatic hydrocarbons (PAHs); pet, human and cooking odors; ETS; volatile organic compounds (VOCs); microbial VOCs; and mycotoxins. Many of these substances also produce odors, some of which are pleasant while others can be distracting and irritating. Moisture is included in this category and must be monitored to discourage indoor mold growth.

Volatile organic compounds are prevalent in all indoor environments, with as many as 100 to 1,000 different VOCs in the air. Although VOCs are not visible to the naked eye, exposure to VOCs via inhalation, ingestion or direct contact with the skin, eyes or nasal and throat tissues, can aggravate allergy and asthma symptoms and cause eye, nose and throat irritation; cough; headache; general flu-like illnesses; and skin irritation. Some VOCs also are known to cause cancer and neurological effects.

Volatile organic compounds also can produce irritating odors; for example, trimethylamine from wet fiberglass produces a fishy smell, butyric acid from a ceiling tile may produce a pungent sour odor and styrene from office printers smells rubbery. Musty smells often can be traced to mold, which produces VOCs referred to microbial VOCs.

Exposure to VOCs in offices and other business establishments can cause building occupants to feel uncomfortable, distracted or sick to the point that it interferes with their ability to do their work or reduces their motivation to work (Heerwagen et al). Missed work days or days with reduced activity can cost businesses billions of dollars in lost productivity (Dixon 1985, Fisk 2000, AAAAI 2005). Reducing the level of VOCs also is very important in homes and schools, because children breathe in more air with respect to their body mass than adults and thus have greater exposure to indoor air pollutants. A recent study, for example, found that children exposed to high levels of VOCs were four times more likely to develop asthma (Rumchev et al 2004).

A growing number of scientists also are concerned that exposure to very small traces of VOCs and some industrial chemicals in homes and schools may have profound impacts on fetuses, newborns and children, including disruptions to the endocrine system (hormones), gene activation and brain development. An especially striking finding is some chemicals may have health impacts at extremely low levels, which are not seen at higher levels. Minute levels of phthalates, for example, which are used to make toys, building materials, drug capsules, cosmetics and perfumes, have been linked to sperm damage in men and genital changes, asthma and allergies in children (Waldman 2005).

Researchers at the University of London suspected that small amounts of some environmental chemicals might have a dramatic effect on hormone levels. They tested the hormonal strength of 11 common chemicals, known to mimic estrogen. Alone, each chemical was very weak, but when low doses were mixed with natural estrogen, the strength of estrogen doubled (Waldman 2005, Rajapakse et al 2002). High levels of estrogen are associated with some forms of cancer and developmental problems during puberty.

At this time, research in this area is still very new, and as yet results do not present a clear picture. One upcoming study of particular note is the planned National Children's Study, sponsored by the US Environmental Protection Agency and the Centers for Disease Control and Prevention. About 100,000 children at various ages from birth to puberty will participate in this study. Among the primary goals is to investigate the associations between exposures to environmental pollutants, such as VOCs among others, and adverse health outcomes, especially asthma, autism, attention deficit disorder and alterations at puberty caused by hormonal disruptions, among other neurobehavioral and neurocognitive disorders (Özkaynak et al 2005).

Some types of mold also emit VOCs, known as microbial VOCs or MVOCs, which are responsible for the characteristic musty, earthy odors associated with mold. People who are sensitive to MVOCs may experience eye, nose and throat irritation. A wide variety of molds also can produce mycotoxins at various times during their lifecycles. Building occupants can experience potentially serious health problems if they are exposed to high levels of these compounds, but this is rare in most indoor environments.

Although becoming a lesser issue in public buildings, ETS is still found in many homes, hotels, casinos, and in some restaurants and bars. Environmental tobacco smoke alone contains more than 4,700 airborne substances, including gases and particles from incompletely burned tobacco, of which 243 are known carcinogens.

IAQ vs. Energy Conservation: Competitive or Complementary Goals

Americans consume about 70 percent more energy per dollar of gross domestic product (GDP) than do people in most other developed countries. In 2000, Americans spent (directly or indirectly) about $600 billion on energy of all kinds. Residential energy consumption in 2000 accounted for 20 percent, commercial 17 percent, industrial 36 percent, and transportation 27 percent of energy consumed in 2000, which is almost identical to that in 1990 (Joskow 2001).

Even so, a building designed since the late 1990s uses less than one-half the energy consumed on a per-square-foot basis than a building designed in 1970 (Ross 2007). The key difference is that there are many more buildings today. One-half of all commercial buildings in the US were built during or after the 1970s, with commercial buildings comprising nearly 70 percent of all buildings in the US.

The indoor environmental factors that most influence occupant health and welfare are thermal conditions, lighting and concentrations of indoor pollutants. Energy professionals are in a strong position to affect thermal conditions and lighting, while they are often less knowledgeable about indoor pollutants. As noted, to achieve energy efficiency goals, very often ventilation rates are reduced to the detriment the quality of the indoor air and the building occupants breathing that air, thus supporting the misconception that providing good IAQ and energy conservation are competing goals.

Compounding the misconception is the energy required to operate the HVAC system is about one-half of a building's energy cost. Since energy efficiency can reduce operating costs, and because the burning of fossil fuels is a major source of greenhouse gases, energy conservation has become a matter of public policy. There are some indications, however, that the interdependent relationship between IAQ and energy is gaining acceptance in the public policy arena as evidenced by the increasing number of proposed IAQ-related state legislation in the past several years.

The US EPA's evaluation of energy cost and IAQ performance of ventilation systems and controls addresses this misconception by demonstrating that good IAQ and effective energy conservation can complement each other while providing significant savings and protecting the outdoor environment. According to the US EPA, many energy efficiency measures with the potential to degrade indoor environmental quality appear to require only minor adjustments to protect the indoor environment (US EPA 2000).

In this study, when energy efficiency measures (including lighting upgrades), which were adjusted to either enhance or not degrade indoor environmental quality, were combined with measures to meet the outdoor air requirements as proscribed in ANSI/ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*, total energy costs were cut by 24 percent to 43 percent for the office building and 22 percent to 37 percent for the school. Not included were savings from reduced lighting during unoccupied hours that could provide 12 percent to 22 percent savings, or improved equipment operations that could provide 5 percent to 15 percent savings (US EPA 2000).

Operational measures that could degrade IAQ, such as widening the daytime temperature dead band, relaxing the nighttime temperature setback and reducing HVAC operating hours, were not included. Cumulatively, these three measures that are not compatible with IEQ would have reduced total energy costs by only three percent to five percent in the office building, and seven percent to ten percent in the school. When compared with the potential savings noted above, the US EPA concluded there is a demonstrable compatibility between indoor environmental and energy efficiency goals, when energy saving measures and retrofits are applied wisely (US EPA 2000).

Newer Objectives – Same Health Impact

Even though the focus today is on saving energy as a key strategy to address concerns about global warming rather than petroleum supply disruptions of the 1970s, the impact of energy conservation measures on IAQ can still cause significant health and comfort issues for building occupants. The difference is there is 40 years of experience and research on which to base decisions and to adopt viable strategies that address both energy conservation and IAQ concerns. As noted at the beginning of this report, to successfully manage IAQ and energy, both must have the same priority throughout the life of a building.

AQS stands ready to partner with the building owners, designers, specifiers, builders, and operation and maintenance personnel to create and maintain healthy indoor environments. Visit us at www.aqs.com to learn more about how the AQS Building Consulting Group can help you, or call us at (770) 933-0638. Also visit the AQS Aerias IAQ Resource Center to learn more about indoor air quality. Aerias may be accessed from the AQS website or at www.aerias.org. For a listing of products that are certified to emit low levels of VOCs, visit the GREENGUARD Environmental Institute site at www.greenguard.org.

Citations

Addington DM. The History and Future of Ventilation. Chapter 2 IN: Indoor Air Quality Handbook. Eds: Spengler JD; Samet JM and McCarthy JF. McGraw Hill. New York. 2000.

ALA Special Report on Air Cleaners: Types, Effectiveness and Health Impact. Available online at www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=39289. Accessed January 31, 2006.

American Academy of Allergy, Asthma and Immunology. Asthma Statistics Media Kit. Available online at www.aaaai.org/media/resources/media_kit/asthma_statistics.stm. Accessed May 19, 2005.

Brightman HS, Womble SE, Girman JR et al. Preliminary comparison of questionnaire data from two IAQ studies: occupant and workspace characteristics of randomly selected buildings and complaint buildings. Proceedings of Healthy Buildings: IAQ 1997. 2: 453 – 458. Washington, DC. As reported in Fisk 2000.

Dixon RE. Economic costs of respiratory tract infections in the United States. Am J Med. 78(6B): 45 – 51. As reported in Fisk 2000.

Fisk, WJ. 2000. Estimates of potential nationwide productivity and health benefits from better indoor environments: an update. IN: Indoor Air Quality Handbook, Chapter 4. Eds John D. Spengler, Jonathan M. Samet , John F. McCarthy. McGraw Hill. New York, New York. 2000.

Fisk, WJ, Rosenfeld AH. 1997. Estimates of improved productivity and health from better indoor environments. Indoor Air '97 7: 158-172.

Heerwagen, Johnson, Brothers et al. Energy Effectiveness and the Ecology of Work: Links to Productivity and Well Being. Energy Effectiveness and the Ecology of Work: Links to Productivity and Well-Being -8.123.

Joskow PL. US Energy Policy During the 1990s. Presented at the "American Economic Policy During the 1990s" conference, sponsored by the John F. Kennedy School of Government, Harvard University. Cambridge, Massachusetts. June 27 to June 30, 2001. Available online at http://web.mit.edu/ceepr/www/2001-004.pdf.

Kumar S and Fisk, WJ. 2002. The Role of Emerging Energy Efficient Technology in Promoting Workplace Productivity and Health: Final Report. Lawrence Berkeley National Laboratory. February 13, 2002, pp. 20-21. Available online at www.library.lbl.gov/docs/LBNL/497/06/PDF/LBNL-49706.pdf.

McDonald B and Ouyang M. Air Cleaning – Particles. Chapter 9 IN: *Indoor Air Quality Handbook*. Eds: Spengler JD; Samet JM and McCarthy JF. McGraw Hill. New York. 2000.

Özkaynak H, Whyatt RM, Needham LL et al. Exposure assessment implications for the design and implementation of the National Children's Study. Environ Health Perspect. 113 (8): 1108 – 1115. August 2005.

Rajapakse N, Silva E, and Kortenkamp A. Combining xenoestrogens at levels below individual no-observed-effect concentrations dramatically enhances steroid hormone action. Environ Health Perspect. 110:917– 921 (August 2002).

Ross DE. Greatest Engineering Achievements of the 20th Century: Air Conditioning and Refrigeration Essay. National Academy of Engineering. Washington, DC. 2007. Available online at www.greatachievements.org/?id=3856.

Rumchev K, Spickett J, Bulsara M et al. Association of domestic exposure to volatile organic compounds with asthma in young children. Thorax. 59: 746 – 751. 2004.

Waldman, P. Levels of risk. Common industrial chemicals in tiny does raise health issues. *The Wall Street Journal*. New York, NY. July 25, 2005.

Wulfinghoff DR. The Modern History Of Energy Conservation: An Overview for Information Professionals. Electronic Green Journal. Vol 13. December 2000. University of Idaho Library. Moscow, Idaho. Available online at http://egj.lib.uidaho.edu/egj13/wulfinghoff1.html.

US Environmental Protection Agency. Energy cost and IAQ performance of ventilation systems and controls. Indoor Environments Division. Office of Radtional and Indoor Air Office of Air and Radiation. Washington, D.C. January 2000. Available online at www.epa.gov/iaq/largebldgs/eiaq_page.htm.

US Green Building Council. Buildings and Climate Change. US Green Building Council. Washington, DC. Accessed July 23, 2007. Available online at www.usgbc.org/DisplayPage.aspx?CMSPageID=1617.

US Green Building Council. Green Building Fact Sheet. US Green Building Council. Washington, DC. Available at www.usgbc.org/DisplayPage.aspx?CMSPageID=97&. Accessed June 10, 2005 and August 22, 2007..

Yudelson J. Perspective: Forecasting market demand for green buildings 2004 – 2007. , Environmental Design + Construction Magazine. December 2004. Available at www.edcmag.com. Accessed June 10, 2005.