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How IEQ Affects Health, Productivity.

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Introduction

This article, a summary of Fisk (2000a, 2000b), estimates the nationwide improvements in health and productivity potentially attainable by providing better indoor environmental quality (IEQ) in U.S. buildings. Estimates include the potential reductions in three categories of health effects, the associated economic benefits, and the potential direct improvements in productivity not mediated through health. Expected costs and benefits of improving IEQ are compared, with a brief discussion of energy implications.

Methods

Potential percentage reductions in health effects from changes to buildings and IEQ were estimated from the results of epidemiologic (i.e., population health) studies that identified risk factors for health effects and quantified the risks. For example, many studies have found that the prevalences of respiratory symptoms associated with asthma are increased by 20% to 100% among occupants of houses with moisture problems, implying that elimination of these moisture problems would diminish symptoms by 17% to 50% in these occupants [e.g., $20\%/120\%=17\%$]. The degree to which these risk factors could be reduced through practical measures was estimated from published data, using engineering judgements. For example, it was considered technically feasible and practical, but not necessarily easy or inexpensive, to double ventilation rates in offices or to improve prevention and expedite repair of water leaks in buildings. Consequently, the “potential” reductions in risk factors in this paper are those considered both technically feasible and practical, recognizing that implementation costs and other barriers will sometimes make these gains difficult to realize.

To calculate health benefits, potential percentage reductions in health effects were multiplied by the size of the affected population or by the number of health effects experienced. To estimate economic benefits, the percentage reductions in health effects were multiplied by the annual costs of the health effects. The costs in the U.S. of acute respiratory illnesses and of allergies and asthma were based on published estimates incorporating both direct health care costs and indirect productivity costs (e.g., value of lost work). Estimating the costs of sick building syndrome (SBS) symptoms was more difficult and produced more uncertain estimates. No comprehensive data were available on the costs of SBS-related investigations, remediations, or litigation; however, three studies have measured small but statistically significant decreases in worker performance linked to SBS symptoms. Therefore, the estimated cost of SBS symptoms was based on these measured decreases in work performance (adjusted downward as explained in Fisk (2000a)) and on the economic output of office workers, since SBS is most commonly reported for office workers.

A similar procedure was used to estimate the potential direct productivity gains from improved indoor temperature control and better lighting quality. All estimates were adjusted to 1996 dollars and to the size of the U.S. population in 1996.

Results

Acute Respiratory Illness (ARI)

No high quality studies identified had investigated but failed to find a link between building characteristics and acute respiratory illnesses (ARIs) such as influenza and common colds. Eight studies reported statistically significant 23% to 76% reductions in ARIs among occupants of buildings with higher ventilation rates, reduced space sharing, reduced occupant density, or irradiation of air with ultraviolet light. These changes to buildings or building use were considered technically feasible and practical, given sufficient benefits. One study found a 35% reduction in short-term absence, a surrogate for ARI, in buildings with higher ventilation rates. Because some of these studies took place in unusual building types, such as barracks and a jail, reductions in ARIs were adjusted downwards, and ranged from 9% to 20%. Multiplying this range by the annual cases of common colds and influenza resulted in an estimated 16 million to 37 million potentially avoided cases of common cold and influenza. Given the \$70 billion annual cost of ARIs, the associated potential productivity gains were \$6 billion to \$14 billion.

Allergies and Asthma

The scientific literature reports statistically significant links between prevalences of allergy and asthma symptoms and a variety of changeable building characteristics or practices, including indoor allergen concentrations, moisture and mold problems, pets, and tobacco smoking. The reported links between these risk factors and symptoms were often quite strong. For example, parental smoking was typically associated with 20% to 40% increases in asthma symptoms. In numerous studies, mold or moisture problems in residences were associated with 100% increases in lower respiratory symptoms indicative of asthma. These moisture and mold problems are common; for example, about 20% of U.S. houses have water leaks. Based on these data, the estimated potential reduction in allergy and asthma symptoms from improved IEQ was 8% to 25%, among a large population -- 53 million with allergies and 16 million asthmatics. Given the \$15 billion annual cost of allergies and asthma, the potential economic gains are \$1 billion to \$ 4 billion.

Sick Building Syndrome (SBS) Symptoms

SBS symptoms are acute symptoms, such as eye and nose irritation and headache, associated with occupancy in a specific building, but not indicating a specific disease. Risk factors for SBS symptoms identified in many studies include lower ventilation rates, presence of air conditioning, and higher indoor air temperatures. Increased chemical and microbiological pollutants in the air or on indoor surfaces, debris or moisture problems in HVAC systems, more carpets and fabrics, and less frequent vacuuming were risk factors in a smaller number of studies. One large study suggests that a 10 cfm per person increase in ventilation rates would decrease prevalences of the most common SBS symptoms on average by one third. Practical measures could diminish all these risk factors. Based on these data, the estimated potential reduction in SBS symptoms was 20% to 50%. The affected population is very large – in a survey of 100 U.S. offices, 23% of office workers (64 million workers) frequently experienced two or more SBS symptoms at work. The estimated productivity decrement caused by SBS symptoms in the office worker population was 2%, with an annual cost of \$60 billion. A 20-50% reduction in these symptoms, considered feasible and practical, would bring annual economic benefits of \$10 billion to \$30 billion.

Direct Productivity Gains

Published literature documents direct linkages of worker performance with air temperatures and lighting conditions, without apparent effects on worker health. Many but not all studies indicate that small (few °C) differences in temperatures can influence workers' speed or accuracy by 2% to 20% in tasks such as typewriting, learning performance, reading speed, multiplication speed, and word memory. Surveys have documented that indoor air temperature is often poorly controlled, implying an opportunity to increase productivity. Wyon (1996) estimated that providing $\pm 3^{\circ}\text{C}$ of individual temperature control would increase work performance by 3% to 7%. A smaller number of studies have documented improvements in work performance with better lighting, with benefits most apparent for visually demanding work. Increased daylighting was also linked in one study to improved student learning. Based on these studies and

recognizing that performance of only some work tasks is likely to be sensitive to temperature and lighting, the estimated potential direct productivity gain is 0.5% to 5%, with the factor of ten range reflecting the large uncertainty. Considering only U.S. office workers, the corresponding annual productivity gain is \$20 billion to \$200 billion.

Benefits and Costs of Improving Indoor Environments

Two example calculations compared estimated productivity gains with costs for increasing ventilation rates and increasing filter system efficiency. The benefit-to-cost ratios were 14 and 8, respectively. Milton et al. (2000) estimated benefit-to-cost ratios of three to six for the reduced absence obtained with increased ventilation, neglecting diminished health care costs. For many other measures that increase productivity, we would expect similarly high benefit-to-cost ratios. For example, preventing or repairing roof leaks should diminish the need for costly building repairs in addition to reducing asthma symptoms. Some measures, such as removing pets from houses of asthmatics, have negligible financial costs.

Productivity Gains and Energy Efficiency

In many non-industrial workplaces, the cost of workers' salaries and benefits exceeds energy costs by approximately a factor of 100. Consequently, businesses should be strongly motivated to change building designs or operations if these changes improved worker performance by even a significant fraction of a percent or reduced sick leave by a day or more per year. While employers may be tempted to neglect energy efficiency when seeking to improve health and productivity, the most desirable measures or packages of measures are those that improve IEQ and simultaneously save energy. Examples of such measures are provided in Fisk (2000a).

Summary

Table 1 summarizes the estimated potential health and productivity gains from improved IEQ. While uncertainty in the magnitude of potential gains is high, even the lower bounds of the estimated benefits are very large from a societal perspective.

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Table 1. Estimated potential productivity gains from improvements in indoor environments.

Source of Productivity Gain	Potential Annual Health Benefits	Potential U.S. Annual Savings or Productivity Gain (1996 \$U.S.)
Reduced respiratory illness	16 to 37 million avoided cases of common cold or influenza	\$6 - \$14 billion
Reduced allergies and asthma	8% to 25% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	\$1 - \$4 billion
Reduced sick building syndrome symptoms	20% to 50% reduction in SBS health symptoms experienced frequently at work by ~15 million workers	\$10 - \$30 billion
Improved worker performance from changes in thermal environment and lighting	Not applicable	\$20 - \$160 billion