Potential Nationwide Improvements in Productivity and Health From Better Indoor Environments

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ABSTRACT

Theoretical considerations and empirical data suggest that existing technologies and procedures can improve indoor environments in a manner that significantly increases productivity and health. Existing literature contains moderate to strong evidence that characteristics of buildings and indoor environments significantly influence rates of respiratory disease, allergy and asthma symptoms, sick building symptoms, and worker performance. While there is considerable uncertainty in our estimates of the magnitudes of productivity gains that may be obtained by providing better indoor environments, the projected gains are very large. For the U.S., we estimate potential annual savings and productivity gains of \$6 to \$19 billion from reduced respiratory disease, \$1 to \$4 billion from reduced allergies and asthma, \$10 to \$20 billion from reduced sick building syndrome symptoms, and \$12 to \$125 billion from direct improvements in worker performance that are unrelated to health. In two example calculations, the potential financial benefits of improving indoor environments exceed costs by a factor of 8 and 14. Productivity gains that are quantified and demonstrated could serve as a strong stimulus for energy efficiency measures that simultaneously improve the indoor environment.

Introduction and Approach

Prior literature on the relationship of indoor environments to productivity has focused primarily on potential direct improvements in worker's cognitive or physical performance from changes in temperatures or lighting. Current evidence suggests at least three additional major links between health and productivity and the indoor environment, where we spend 90% of our lives links. These links are infectious disease, allergies and asthma, and acute sick building syndrome symptoms. Reductions in these health effects will decrease health care costs and the costs of sick leave and reduced performance due to illness.

The primary purpose of this paper is to synthesize available information pertaining to the linkages between the indoor environment and health and productivity and, based on this synthesis, to develop credible estimates of the total productivity gains that might result from better indoor environments. We recognize that existing data are adequate only for approximate estimates of potential productivity gains; however, even imprecise unbiased estimates should be of considerable value to policy makers and researchers.

Computer literature searches and personal contacts were used to identify relevant papers and the evidence supporting or refuting the hypothesized linkages was synthesized. The economic costs of adverse health effects linked to the indoor environment were estimated from the results of previous analyses and supplemented by performing new calculations. The economic results of previous analyses were updated to 1993 to account for general inflation, health care inflation, and increases in population (U.S. Department of Commerce 1995). The next and most uncertain step in the analysis was to estimate the magnitude of the decrease in adverse health effects and the magnitude of direct improvements in productivity that might result from improved indoor environments. These estimates are based on findings reported in the literature, our understanding of the linkages, and our understanding of the degree to which relevant indoor environmental conditions could practically be improved. Next, cost savings from reduced health effects were estimated by multiplying the estimated percentage decrease in adverse health effects with the total health care costs, absence costs, and productivity losses attributed to these health effects. Direct productivity gains, i.e., gains unrelated to health, were estimated by multiplying the estimated percentage increase in productivity with the magnitude of the associated economic activity.

To make this paper understandable to a relatively broad audience, we have minimized the use of unfamiliar statistical terminology. The findings reported in this paper would generally be considered to be statistically significant (e.g., the probability that findings are due to chance or coincidence is generally less than 5%). Measures of statistical significance are included in Fisk and Rosenfeld (1997) on which much of this paper is based.

Results and Discussion

In this section, linkages between indoor environmental quality (IEQ) and health and productivity are reviewed and the magnitudes of potential productivity gains associated with each linkage are estimated. Then, for two examples, the costs of improving indoor environments are compared to the value of productivity gains. Finally, the potential to use productivity gains to stimulate energy efficiency is discussed.

Infectious Disease Transmission

Linkage. Several field studies provide evidence that building characteristics significantly influence disease incidence. In a large multi-year study performed by the U.S. Army (Brundage et al. 1988), rates of acute respiratory disease with fever were 50% higher among recruits housed in newer barracks with closed windows, low rates of outside air supply, and extensive air recirculation compared to recruits housed in older barracks with frequently open windows, more outside air, and less recirculation. In a study of office workers (Jaakkola et al. 1993), workers with one or more roommates were 20% more likely to have more than two cases of the common cold during the previous year than workers with no roommates. At an Antarctic station, the incidence of respiratory illness was twice as high in the population housed in smaller (presumably more densely populated) living units (Warshauer et al. 1989). In an older study, (N.Y. State Commission on Ventilation 1923), there were 170% as many respiratory illnesses and 118% as many absences from illness in fan-ventilated classrooms compared to window-ventilated classrooms, despite a lower occupant density in the fan-ventilated rooms. Classroom ventilation rates were not measured. Another study investigated symptoms associated with infectious illness among 2598 combat troops in Saudia Arabia (Richards et al. 1993). The type of housing (air-conditioned buildings, non-air-conditioned buildings, open warehouses, and tents) significantly influenced the incidence of symptoms associated with respiratory disease with the highest incidence in the air-conditioned buildings that presumably have the lowest ventilation rates. Finally, an epidemic of pneumococcal disease in a jail was studied by Hoge et al. (1994). There were significantly fewer cases of disease among inmates with 7.4 m^2 or more of space. The disease attack rate was about 95% higher in the cells with the highest carbon dioxide concentrations and the lowest supply of outside air.

Cost of Infectious Respiratory Disease. In the U.S., upper respiratory disease causes about 160 million days lost from work and 300 million workdays of restricted activity (Garibaldi 1985, Dixon 1985, adjusted for population gain). Assuming a 100% and 25% decrease in productivity on lost-work and restricted-activity days, respectively, and a $36K average annual compensation (U.S. Department of Commerce 1995), the annual value of lost work is approximately $35 billion. The annual health care costs for respiratory tract infections in the total US population is about $29 billion (Dixon 1985, adjusted for population gain and health care inflation), thus the total annual cost of respiratory infections is approximately $64 billion.

Potential Savings. An ability to substantially change the building-related factors that influence disease transmission is critical to the realization of the associated health care cost savings and productivity gains. A number of practical building technologies, such as increased ventilation, reduced air recirculation, improved filtration, ultraviolet disinfection of air, and reduced space sharing have the theoretical potential to reduce peoples' inhalation exposures of infectious aerosols by more than a factor of two. Also, if occupant density is confirmed as an important factor, it can be decreased.

The studies cited above suggest that building characteristics can change rates of respiratory disease by approximately 20% to 100%, with the strongest study (Brundage et al. 1988) yielding a change of 50%. The amount of time spent in a building should influence the probability of disease transmission within the building. The period of occupancy in the studies cited above ranged from approximately 40 hr per week (24% time) in offices and schools to 100% time in jails. If efforts to reduce disease transmission were implemented primarily in commercial and institutional buildings that people occupy approximately 40 hours per week, smaller reductions in respiratory disease would be expected in the general population than indicated by the research literature. Using the methods described in Fisk and Rosenfeld (1997), we adjusted the reported increases in respiratory disease for time spent in buildings, yielding the increase expected for 40 hour per week occupancy. After this adjustment, the studies cited above suggest that building characteristics change the rates of respiratory disease by approximately 10% to 70%. The range is 10% to 30% if the outlier factor of 70% from the study of schools is neglected. We adopt this narrower range, i.e., 10% to 30%, for the potential reduction in respiratory disease. The corresponding annual economic benefit is of $6 to $19 billion.

Allergies and Asthma

Linkage. 20% of the U.S. population have environmental allergies and 10% have asthma (Committee on Health Effects of Indoor Allergens 1993). The prevalence of asthma, asthma-related hospitalization, and asthma-related mortality is increasing substantially. The symptoms of allergies and of the portion of asthma caused by airborne allergens can be triggered by allergens in indoor air including fragments of house dust mites, allergens from pets, fungi, and insects, and pollens that enter buildings from outdoors. Several studies indicate that occupants of homes, schools, or offices with evidence of dampness (or presence of molds) have approximately a 30% to 50% higher prevalence of asthma or lower respiratory symptoms (e.g., Spengler et al. 1993, Division of Respiratory Disease Studies 1984). Asthma symptoms may be triggered by irritating chemicals including environmental tobacco smoke (Evans et al. 1987) and by infectious respiratory diseases. Thus, the evidence of a linkage between the quality of the indoor environment and the incidence of allergic and asthma symptoms is strong.

Cost of allergies and asthma. The estimated cost of asthma-related illness in the total US population (i.e., both the workforce and others) during 1990 was $6.2 billion (Weiss et al. 1992) which includes $3.6 billion in medical expenditures and $2.6 billion in indirect costs, e.g., loss of work. Neglecting increases in asthma prevalence but adjusting for population gain, for general inflation of indirect costs, and for health care inflation of medical costs, yields an estimated total cost in 1993 of $7.9 billion. McMenamin (1995) estimated the health care and indirect costs of allergic rhinitis plus the cost of the portion of four airway disorders allocable to allergy. Excluding the portion of these costs associated with asthma (since asthma costs are included in the estimate by Weiss et al. 1992) and adjusting to 1993 yields a cost of $4.9 billion. Combining this figure with the asthma cost yields an annual total of $12.8 billion.

Potential Savings from Changes in Building Factors. Many of the exposures that elicit symptoms of allergies and asthma are allergens in the form of airborne particles. Technologies for reducing indoor concentrations of airborne particles generated indoors are readily available (e.g., better air filtration and increased ventilation). Better filtration of the outside air entering buildings can also greatly diminish the entry of outdoor allergens into buildings. Some allergens are large particles that are less effectively controlled by air filtration (because of their high settling rates); however, exposures to allergens may also be decreased by reducing indoor allergen sources through better cleaning practices, elimination of surfaces most likely to be allergen reservoirs (e.g., carpets), and better control of indoor moisture (e.g., water leaks). Chemical exposures that elicit asthma symptoms can be decreased by limiting sources (e.g. smoking) or through better ventilation. Reduced respiratory infections will also reduce asthma symptoms. Thus, there is a strong theoretical basis for the hypothesis that improving indoor environments can substantially decrease the symptoms of allergies and asthma.

Various measures have been effective in reducing indoor concentrations of allergens. Unfortunately, we identified few published studies of the effect of changes in building conditions on the symptoms of allergies and asthma. Measures to reduce exposures to dust mite allergen have reduced symptoms in some studies (see Fisk and Rosenfeld 1997). Nelson et al. (1988) reviewed research on the use of residential air cleaning devices to treat allergic respiratory disease. All nine of the studies reviewed indicated that air filtration devices and air conditioning reduced seasonal allergic symptoms, but the subjects of most studies were not blinded (i.e., were not unaware of the air filtration). For perennial allergic disease, six of eight studies suggest improvement with air filtration. Despite the generally positive results, Nelson et al (1988) indicated that current data were inadequate to recommend the use of air cleaners.

With the limited data available, it is tempting to conclude that no estimate of potential savings is possible. However, the theoretical basis for the hypothesis that improving indoor environments can substantially decrease symptoms of allergies and asthma is strong and this hypothesis is supported by the limited experimental data that are available. The most credible estimate of savings is clearly greater than zero. Through implementation of suitable control measures, reductions in indoor allergen exposures by more than 50% should be readily attainable. Control measures can be targeted at the homes or offices of susceptible individuals. We estimate that a 10% to 30% reduction in symptoms and associated costs is practical. With this estimate, the annual savings would be ~$ 1 to 4 Billion.

Sick Building Syndrome Symptoms

Linkage. Characteristics of buildings and indoor environments have been linked to the prevalence of acute health symptoms among office workers, often called sick building syndrome (SBS) symptoms. These symptoms include irritation of eyes, nose, and skin, headache, and fatigue. The existing literature suggests that these symptoms are experienced by a substantial fraction of all office workers (e.g. 5% to 40% of workers depending on the symptom), not just by workers in the well publicized sick buildings (e.g., Fisk et al. 1993). Although psychosocial factors such as job stress influence SBS symptoms, several characteristics of buildings and indoor environments are also known or suspected to influence these symptoms including: the type of building ventilation system, type or existence of humidification equipment, rate of outside air ventilation, the indoor chemical and microbiological pollution, and indoor temperature and humidity (e.g., Mendell 1993). SBS symptoms have been reduced through increased ventilation, decreased temperature, and improved cleaning of floors and chairs (Mendell 1993).

Cost of SBS Symptoms. SBS symptoms are a distraction from work and can lead to absence from work (Preller et al. 1990) and visits to doctors. When investigations of the building are required, there are financial costs to support the investigations and considerable effort is typically expended by building staff. Responses to SBS have included costly changes in the building and litigation. Our calculations indicate that the costs of small decreases in productivity from SBS symptoms are likely to dominate the total SBS cost. Limited information is available that provides an indication of the influence of SBS symptoms on worker productivity. Self-reported productivity losses from SBS symptoms have usually been approximately 4% (Fisk and Rosenfeld 1997). In a study by Nunes et al. (1993), workers that reported SBS symptoms took 7% longer to respond in a computerized neurobehavioral test and had a 30% higher error rate in a second computerized neurobehavioral test.

The data of Nunes et al. (1993) provide substantial evidence that SBS symptoms actually decrease performance; however, it is difficult to relate the decrements in performance in the computerized tests to the magnitude of an overall productivity decrement from SBS symptoms. The self reports suggest a productivity decrease of approximately 4% (average for entire workforce) due to poor indoor air quality and physical conditions at work. Although SBS symptoms are the most common work-related health concern of office workers, some of this self-reported productivity decrement may be a consequence of other factors. Also, workers who are unhappy with the indoor environment may have provided exaggerated estimates of productivity decreases. To account for these factors, we discount the 4% productivity decrease cited above by a factor of two, leading to an estimate of the average productivity decrease caused by SBS equal to 2%, recognizing that this estimate is highly uncertain. Since SBS is primarily associated with office workers with an annual gross national product of $2.5 trillion (Traynor et al. 1993), the estimated annual cost of SBS is $50 billion.

Potential Savings from Changes in Building Factors. Because multiple factors, including psychosocial factors, contribute to SBS symptoms, we can not expect to eliminate SBS symptoms and SBS-related costs. However, the numerous findings (Mendell 1993, Sundell 1994) of associations between SBS symptoms and building and environmental factors, together with our knowledge of methods to change building and environmental conditions, are evidence that SBS symptoms can be reduced. Many studies, from buildings without known SBS problems, have found individual environmental factors and building characteristics to be associated with changes of 20% to 50% in the prevalence of individual SBS symptoms or groups of related symptoms. In a few blinded experimental studies (reviewed in Mendell 1993, Sundell 1994), specific indoor environmental conditions have been changed to investigate their influence on symptoms. Some of these studies have also demonstrated that increased ventilation rate, decreased temperature, and better surface cleaning, and use of ionizers can diminish SBS symptoms, while no significant benefit was evident in other studies. In summary, the existing evidence suggests that 20% to 50% reductions in SBS symptoms should be possible. The corresponding annual productivity increase is of the order of $10 to $20 billion.

Direct Impacts of Indoor Environments on Human Performance

Background. Indoor environmental conditions may directly influence the performance of physical and mental work, without influencing health symptoms. This section discusses the evidence of a direct connection between worker performance and thermal conditions and lighting. Existing standards define the boundaries of recommended thermal and lighting conditions because conditions far from optimal have an obvious adverse influence on comfort and performance. Research on this topic is difficult because of the complexity of defining and measuring performance in real-world environments and because many factors, including worker motivation, influence performance. Indicators of human performance have included measures of actual work performance, results of tests of component skills (e.g., reading comprehension) relevant to work, and subjective self-estimates of performance changes.

Linkage between thermal environment and performance. Wyon (1996) and Fisk and Rosenfeld (1997) summarize of the literature on the relationship of temperature to mental performance and light manual work. The literature indicates that changes in temperature of a few degrees Celsius within the 18 °C to 30 °C range can significantly influence performance in several tasks including: typewriting, factory work, signal recognition, time to respond to signals, learning performance, reading speed and comprehension, multiplication speed, and word memory. However, not all studies have found such associations. For complex or creative mental work, optimal thermal comfort and optimum performance may approximately coincide. For other types of mental work, slight thermal discomfort that increases arousal (e.g., slightly cool temperatures) may increase performance (Wyon 1996). Given that the optimum temperature depends on the nature of the task, will vary among individuals, and will vary over time, some papers have advocated the provision of individual control of temperature as a practical method to increase productivity (Kroner and Stark 1992, Wyon 1996b). A study in an insurance office (Kroner and Stark 1992) suggested that provision of individual temperature control increased productivity by approximately 2%. However, studies of individual control can not be performed blindly. Wyon (1996b) has estimated that providing workers ± 3 °C of individual control should lead to about a 3% increase in performance for both logical thinking and very skilled manual work, and approximately a 7% increase in performance for typing relative to performance in a building maintained at the population-average neutral temperature.

Linkage between lighting and human performance: Lighting has at least the theoretical potential to influence performance directly, because work performance depends on vision, and indirectly, because lighting may direct attention, or influence arousal or motivation NEMA (1989). Obviously, lighting extremes will adversely influence performance; however, the potential to improve performance by changing the lighting normally experienced within buildings is the most relevant question for this paper.

It is expected that performance of work that depends very highly on excellent vision, such as difficult inspections of products, will vary with lighting levels and quality. The published literature, while limited, is consistent with this expectation. For example, Romm (1994) reports a 6% increase in the performance of postal workers during mail sorting after a lighting retrofit that improved lighting quality and also saved energy. NEMA (1989) provides additional examples. Several studies have shown that subjects' performance on special visual tests can vary as a function of illuminance and spectral distribution of light (Fisk and Rosenfeld 1997). Some studies have found statistically significant effects of illuminance on aspects of reading; however, performance reductions were primarily associated with unusually low light levels or reading material with small, poor-quality, or low-contrast type (Fisk and Rosenfeld 1997). A few studies have examined the influence of different lighting systems on self-reported productivity or on cognitive task performance (Fisk and Rosenfeld 1997). These studies indicate that occupant satisfaction and self-reported productivity may increase; however, evidence that actual work performance will increase is quite limited.

Potential value of productivity gains. Extrapolations from the laboratory studies to the work force are the only avenue presently available to estimate the direct work performance improvements that could be obtained from improvements in indoor environments. There are reasons for estimating that productivity increases in practice will be smaller than the percentage changes in performance in the research literature. First, some of the measures of performance, such as error rates and numbers of missed signals, are not readily related to overall changes in productivity (e.g., decreasing an error rate by 50% usually does not increase productivity by 50%). Second, research has often focused on tasks that require excellent concentration, quick responses, or excellent vision while most workers spend only a fraction of their time on these tasks. Third, the changes in temperatures and illuminance within many studies are larger than average changes in conditions that would be made in the building stock.

To estimate potential productivity gains, we consider only the reported changes in performance that are related to overall productivity in a straightforward manner, e.g., reading speed and time to complete assignments are considered but not error rates. The literature reports performance changes of 2% to 20% (neglecting one 49% improvement). We assume that only half of work is on tasks likely to be significantly influenced by practical variations of temperature or lighting, thus, the 2% to 20% performance changes are divided by a factor of two. Next, we divide performance by another factor of two because the research has generally been based on large differences in temperature and lighting, often twice as large as the changes in temperature likely to be made in buildings. Based on this logic, the range for potential productivity increases in the building stock becomes 0.5% to 5%. Considering only U.S. office workers, responsible for a GNP of $2.5 trillion (Traynor et al. 1993), the 0.5% to 5% performance gain translates into an annual productivity increase of $12 billion to $125 billion.

The Cost of Improving Indoor Environments

As an example of costs versus benefits of increased, we consider the analyses of Eto and Meyer (1988) involving a large 55,500 m^2 office building and the climate of Washington D.C. Increasing the minimum ventilation rates from 2.5 L/s-person to 10 L/s-occupant increased the projected annual energy costs by $22,400 or $5.80 per person in 1993 prices. The estimated incremental first cost of the HVAC system was $142,000 (2.1%) in 1993 prices. Spreading this first cost over a 15 year period using a 6% real capital recovery factor results in an annual cost of ~$14,600; thus, the total estimated annual cost is ~$37,000 or $9.50 per person. The annual total compensation for the 3880 office workers in this building will be approximately $140 million ($36K per person). If the increased ventilation leads to a 10% reduction in respiratory infections, the days of lost work and reduced performance at work will decrease by 10%. Since respiratory infections cause workers to miss work about 1.4 days per year and to have 2.2 days of restricted activity, the annual value to the employer would be $ 113,000 [0.1 x (3880 x $36,000 / 240 work days) x (1.4 + (0.25 x 2.2))]. Additionally, health care costs would be reduced by roughly $36,200 annually [0.1 x 3880 x $126 per respiratory condition x 0.74 conditions per year]. If the increased ventilation decreases the productivity loss from SBS symptoms by 0.25%, the associated annual productivity increase is $349,000. Combining the three savings elements yields $ 0.50 million, 14 times the projected annual cost. [In Fisk and Rosenfeld (1997), this calculation contains an error.]

As a second example, we consider improved air filtration which has the potential to decrease infectious disease, allergies and asthma, and SBS symptoms. By installing high-efficiency air filters in an office building, Fisk et al. (1998) reduced the total indoor concentration of submicron-size particles (0.3 µm to 1 µm) by a factor of 10 to 15. Many of these particles have an outdoor origin. The estimated reduction in the concentration of sub-micron indoor-generated particles is a factor of four. The annual cost of purchasing the high efficiency filters is ~$23 per person, assuming an annual filter replacement. The incremental cost of labor is negligible. The increased air-flow resistance of high-efficiency filters can increase the fan power if HVAC air flow rates are maintained unchanged. The increased cost of fan energy is ~$1.00 per person-year based on standard relationships between fan power requirements and air flow resistance, assuming (based on filter product data) that the airflow resistance increases by

60 Pa. In this example, the estimated annual per-person cost of improved air filtration is $24. If the improved filtration resulted in a 10% reduction in respiratory disease, the annual savings would be $38 per worker (see example calculation above for a 3880-person office). If the improved filtration resulted in a 1% increase in the productivity of allergic workers (20% of workforce), the annual productivity gain would be $70 per person averaged over all workers. If the improved filtration decreased the productivity loss from SBS symptoms by 0.25%, the annual productivity gain would be $90 per person. If all of these benefits were realized, the annual savings of ~$200 per worker would exceed the annual cost by a factor of 8.

Productivity Gains as a Stimulus for Energy Efficiency

The previous cost-benefit analyses illustrate that the financial value of productivity gains can be large compared to the associated capital and energy costs. While many (perhaps most) of the building technologies and practices that improve productivity will increase energy use, numerous building technologies and practices have the potential to simultaneously increase productivity and save energy. Therefore, productivity gains that are quantified and demonstrated could serve as a very strong stimulus for the adoption of numerous energy efficiency measures that simultaneously improve the indoor environment. Table 1 provides examples of such energy conservation measures and identifies their most likely influence on the indoor environment when these measures are properly implemented.

Table 1. Examples of energy efficiency measures that often improve indoor environmental quality.

Energy Efficiency Measure	Predominant Influence on Indoor Environment or Productivity
Energy efficient lamps, ballasts, fixtures	Improved lighting quality and occupant satisfaction. Productivity may increase when work is visually demanding.
Outside air economizer for free cooling.	Generally, IEQ will improve due to increase in average ventilation rate. Potential productivity gains from reduced respiratory disease and SBS.
Heat recovery from exhaust ventilation air.	If heat recovery allows increased outside air, IEQ will usually improve. Potential productivity gains from reduced respiratory disease and SBS.
Nighttime pre-cooling using outdoor air.	Nighttime ventilation may decrease indoor concentrations of indoor-generated pollutants when occupants arrive at work, leading to reduced SBS.
Operable windows substitute for air conditioning.	On average, occupants of buildings with natural ventilation and operable windows report fewer SBS symptoms.
Increased thermal insulation in building envelope	Potential increase in thermal comfort because insulation helps HVAC system satisfy thermal loads and because of reduced radiant heat exchange between occupants and building envelope.
Thermally efficient windows.	Improvements in thermal comfort from reductions of drafts and radiant heat exchange between occupants and windows. Reduces condensation on windows and associated risks from growth of microorganisms.

Conclusions

Based on existing literature, there is relatively strong evidence that characteristics of buildings and indoor environments significantly influence rates of respiratory disease, allergy and asthma symptoms, SBS symptoms, and worker performance. There is strong theoretical evidence and limited empirical data, indicating that existing technologies and procedures can improve indoor environments in a manner that increases health and productivity. With existing data and knowledge, we can develop only crude estimates of the productivity gains that may be obtained by providing better indoor environments; however, the projected gains are very large. For the U.S., the estimated potential annual savings plus productivity gains are $30 billion to $170 billion, with a geometric mean of $70 billion and breakdown as indicated in Table 2. Our central estimate of $70 billion in potential annual savings and productivity gains is approximately equivalent to the $88 billion spent in 1993 for energy in the total US commercial building stock. In two example calculations, the potential financial benefits of improving indoor environments exceeded costs by large factors (e.g., factors of 8 and 14). Productivity gains that are quantified and demonstrated could serve as a very strong stimulus for the adoption of numerous energy conservation measures that simultaneously improve the indoor environment.

Table 2. Estimated potential productivity gains from improvements in indoor environments.

Source of Productivity Gain	Strength of Evidence	U.S. Annual Savings or Productivity Gain (1993 $US)
Reduced respiratory disease	Strong	$6 - $19 billion
Reduced allergies and asthma	Moderate	$1 - $4 billion
Reduced sick building syndrome symptoms	Moderate to Strong	$10 - $20 billion
Improved worker performance:		$12 - $125 billion
From changes in thermal environment	Strong	
From changes in lighting	Moderate	
Total Range		$29 - $168 billion
Geometric mean		$70 billion
Total cost of energy in US commercial buildings (for reference)*		$88 billion

* US Department of Energy / Energy Information Agency (1995)

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