Sustainability and Health are Integral Goals for the Built Environment

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Healthy Buildings 2006
Lisbon, Portugal
June 4-8, 2006

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Abstract

The importance of proving that sustainable design and engineering improves health, productivity, and quality of life has never been more important. To this end, the Center for Building Performance and Diagnostics (CBPD) at Carnegie Mellon University, in collaboration with the Advanced Building Systems Integration Consortium*, have been actively developing sustainable design guidelines and a database of laboratory, field, and simulation case studies that reveal the substantial environmental, health and productivity benefits of a range of advanced and innovative building systems. Captured in the Building Investment Decision Support tool (BIDS™), the cost-benefits of investing in a better built environment should drive measurable changes in building design, construction and management. This presentation will explore the health-related benefits of high performance buildings - designed to deliver the highest quality air, thermal control, light, ergonomics, privacy and interaction, as well as access to the natural environment.

Keywords: Sustainability and Health, Sustainable Design for Health, Healthy Building Systems

Definitions of sustainability

Many decisionmakers assume that sustainable design is about resource conservation – energy, water, and material resources. The last ten years, however, has seen a dramatic broadening of the definition of sustainability to include assurances for mobility and access as affected by land use and transportation, for health and productivity as affected by indoor environmental quality, and for the protection of regional strengths as we pursue a more globally shared quality of life. In the US, this broader definition of sustainability is most often ensured through the voluntary LEED™ (Leadership in Energy and Environmental Design) standard of the US Green Building Council. The 69 credits in the LEED for New Construction standard extend beyond the conservation goals of energy, water and materials to include sustainable sites and transportation, outdoor atmosphere, indoor environmental quality and waste.

The Center for Building Performance and Diagnostics at Carnegie Mellon University would argue for expanding this definition even further, to give greater emphasis to contextual and regional design goals, to natural conditioning, and to flexible infrastructures that support change and deconstruction.

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* ABSIC members 2000 to present: Armstrong World Industries, BP Solar, Carnegie Mellon University, US Department of Energy, US Department of Defense, Electricité de France, US Environmental Protection Agency, Gale Foundation, US General Services Administration, Northwest Energy Efficiency Alliance, Public Works and Government Services Canada, Somfy, Siemens Energy and Automation, Inc., Steelcase Inc., Teknion Inc., Tyco Electronics, United Technologies/ Carrier, National Science Foundation.

Seven CBPD Principles for the Design of Sustainable Built Environments

1. Sustainable design depends on an integrative, human-ecological design approach.
2. Sustainable design depends on changing approaches to land-use and community fabric.
3. Sustainable design depends on the effective use of natural, local and global resources to reduce infrastructure loading and maximize infrastructure use.
4. Sustainable design depends on the design of flexible, plug and play systems.
5. Sustainable design depends on the use of sustainable materials and assemblies.
6. Sustainable design depends on design for life-cycle instead of first cost.
7. Sustainable design depends on the promotion of infrastructures to neighborhood amenities.

The CBPD defines sustainable design as “a transdisciplinary, collective design process driven to ensure that the built environment achieves greater levels of ecological balance in new and retrofit construction, towards the long term viability and humanization of architecture. Focusing on environmental context, sustainable design merges the natural, minimum resource conditioning solutions of the past (daylight, solar heat and natural ventilation) with the innovative technologies of the present, into an integrated "intelligent" system that supports individual control with expert negotiation for environmental quality and resource consciousness. Sustainable design rediscovers the social, environmental and technical values of pedestrian, mixed-use communities, fully using existing infrastructures, including "main streets" and small town planning principles, and recapturing indoor-outdoor relationships. Sustainable design avoids the further thinning out of land use, and the dislocated placement of buildings and functions caused by single use zoning. Sustainable design introduces benign, non-polluting materials and assemblies with lower embodied and operating energy requirements, and higher durability and recyclability. Finally, sustainable design offers architecture of long term value through 'forgiving' and modifiable building systems, through life-cycle instead of least-cost investments, and through timeless delight and craftsmanship” [1].

The clarity of the definition of sustainability matters, especially when assessing the relevance of sustainable design, construction, and operations of buildings to long term human and environmental health.

A Definition of Health to be Integral with Sustainable Design

Building on the Cornell Medical Index of 1949 [2], the Center for Building Performance at Carnegie Mellon is using the following ten indices for evaluating the importance of design, construction and operation decisions on human health:

Definition of health integral with sustainable design

1. Respiratory system
2. Digestive system
3. Eyes, vision, irritation, circadian system
4. Ears, hearing damage, concentration
5. Skin
6. Musculo-skeletal
7. Circulatory system
8. Nervous system
9. Genitourinary system
10. Mental health, stress, biophilia

Alternatively, evidence from the research suggests six primary clusters of health issues related to the built environment: respiratory (chest, wheeze, allergies, asthma, colds, flu); mucosal (eye, nose, throat); dermal (face, hand skin); neuro-physiological (headache, migraine, dizziness, heavy-headedness); musculoskeletal; and psychological (SAD, bipolar disorder).

Linking Health and the Built Environment

By setting CBPD's definition of the attributes of sustainable design against the characteristics of human health, even intuitive judgment would illuminate the importance of building design decision making and building operation to human health, as shown in figure 1.

With over 5 years of intense study by faculty, researchers and graduate students, the Center for Building Performance and Diagnostics at Carnegie Mellon and the Advanced Building Systems Integration Consortium have been collecting building case studies as well as laboratory and simulation study results in an effort to statistically link the quality of buildings – system by system – to productivity, health and life cycle sustainability. Amassed in the BIDS™ (Building Investment Decision Support) tool, these case studies enable building decision makers to calculate returns on investments in high performance building systems, and will lead to greater understandings of the importance of land use and buildings to health (see http://cbpd.arc.cmu.edu/ebids).

The following six sections will explore design innovations and life cycle benefits of changes in land use, building massing and enclosure, HVAC engineering, daylight and lighting system design, interior systems, and long-term building maintenance and operations.

Sustainable Land Use and Health

One of the most significant design shifts needed for the long-term health of humans is a shift away from automobile-based land use planning and single use zoning. In industrialized nations, dramatic reductions in transportation by walking and biking may contribute to increasing rates of obesity, while increased reliance upon automobiles has resulted in ever-increasing levels of particulate and ozone that are respiratory hazards. Numerous studies have revealed the seriousness of particulate related health concerns. Wordley et al. [3] identified a 2.4% increase in respiratory admissions and a 2.1% increase in cerebro-vascular admissions associated with a 10 $\mu g/m^3$ increase PM10 in the air. According to Dockery & Pope [4] a 10 $\mu g/m^3$ increase in PM10 in the air increases respiratory admissions by 0.8 ~ 3.4%. Tenias et al. [5] found that a 10 $\mu g/m^3$ increase of NO2 and O3 in the air causes increases in the number of emergency visits for asthma by 7.6% and 6.3%, respectively.

Moreover, automobile-based design is "paving" the countryside, with the elimination of natural landscapes that act as natural lungs for our air and with salting, oils, and storm-sewer overflows resulting in toxic runoff into our drinking water. As a result, it is imperative that sustainable design ensure: live-work-walk lifestyles with mixed-use communities; multi-generational mobility with mixed mode transportation; and the preservation and celebration of natural landscapes and sustainable infrastructures.

Guidelines for Sustainable Land Use for Health

- Design live-work-walk communities to reduce car pollution – particulates and ozone – that trigger asthma
- Design for pedestrian, bicycle, transit mobility to reduce obesity
- Minimize paving for roads and parking, salting and oil runoff, as well as standing water concerns.
- Design landscape dominant environments to reduce thermal heat islands, heat stress, and rebuild natures lungs for air quality

Figure 1. Linking Design Decision making and Health

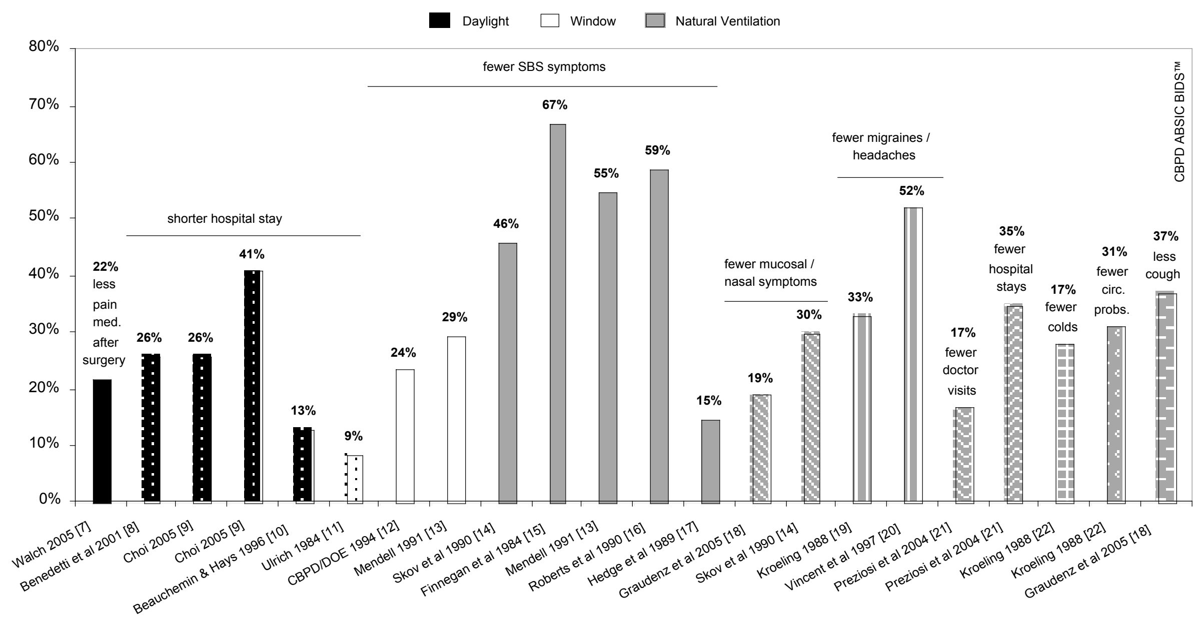
	Respiratory system	Digestive system	Eyes, vision, irritation, circadian system	Ears, hearing damage, concentration,	Skin	Muschulo-skeletal	Circulatory system	Nervous system	Genitourinary system	Mental health, stress, biophilia
Land Use										
Design live-work-walk communities		●				●	●			
Design mixed mode mobility	●	●				●	●			
Increase landscape/ reduce paving	●					●		●		●
Distributed,/renewable power sources	●									
Building Massing and Enclosure										
Design for Daylighting / View / Passive Solar			●					●		●
Design for Natural Ventilation	●									●
Engineer Thermal Load Balancing							●			
Design Enclosure Integrity	●			●			●			
Lighting and HVAC Systems										
Separate ambient and task lighting			●							
Specify high performance lighting & controls			●							
Separate ventilation and thermal conditioning	●						●			●
Increase outside air & ventilation effectiveness	●									
Engineer moisture/humidity management	●				●					
Engineer individual control of temperature							●			
Interior Systems										
Specify ergonomic furniture						●	●			
Design spatial layout/density for health/safety						●				
Specify acoustic quality				●						
Specify materials vs. outgassing/ degradation	●							●		
Specify materials vs. irritation/ re-infection	●	●			●					
Specify materials vs. mold	●									
Operations										
Continuously Commission Systems	●									
Eliminate standing water, dampness and mold	●									
Design for non-toxic pest/ plant management	●	●						●		
Design for environmentally benign cleaning	●				●			●		
Improve food//vending quality for health		●								
Improve water quality for health		●								
Reduce waste/ manage waste vs pests	●									●

Sustainable building massing/ enclosure and Health

After land use design, the second most critical decision for human health may be the design of building massing and its enclosure. Humans need access to the abundances in nature - daylight, natural ventilation, thermal diversity, physical access and views; at the same time, humans need protection from natural stresses – overheating, excessive cold, rain. The design of the building enclosure is critical for both of these.

The CBPD has identified 16 international case studies linking access to the natural environment to improved health outcomes, including reductions in headaches, colds, SBS (Sick Building Syndrome), and patient length of stay (see figure 2). Beyond the health benefits, ten international case studies demonstrate that access to the natural environment increases individual productivity between 3-18% and reduce absenteeism between 9-71%, while 8 studies indicate over 50% (each) lighting and HVAC energy savings [6].

Figure 2. Health Benefits of Access to Nature [7-22]



While the debate continues as to the mechanisms whereby daylight improves health, research continues to reveal that sunlight, especially morning sunlight, reduces length of stay for patients recovering from surgery, bipolar and SAD treatment [7-10]. The work of the Lighting Research Institute at RPI has begun to reveal the relationship of exposure to ultraviolet light and our melatonin production that controls circadian rhythms, sleep cycles and may even slow cancer cell development [23]. The confounding variables of glare and overheating that might accompany uncontrolled sunlight must also be studied.

The importance of views of nature and proximity to windows to human health is equally debated, with the work of Ulrich [11], Mendell [13], and now Kellert [24] identifying a link to reduced length of stay after surgery, sick building syndrome, and overall emotional health and the importance of biophilia. In addition to confirming the importance of seated views for all building occupants, research is critically needed to understand the importance of the content of a window view to health (eg., landscape vs. sky vs. building walls), as well as the benefits of direct access to the outdoors that could accompany views through windows and doors.

The value of increasing outside air delivery rates is becoming increasingly evident, as will be described in HVAC design. It is not clear, however, whether increased levels of outside air are more effectively delivered through operable windows or through mechanical systems that incorporate filtration, dehumidification and thermal conditioning of that outside air. There are over a dozen studies that reveal the benefits of natural ventilation in existing buildings, as compared to mechanical ventilated buildings, in reduced headaches, mucosal symptoms, colds, coughs, circulatory problems, and SBS symptoms. While operable windows can bring in higher quantities of outside air, however, they can also bring in unwanted outdoor pollution, humidity, rain, and noise. The pros and cons of increasing outside air rates through natural versus mechanical means are outlined in figure 3, with a definite emphasis on the value of natural ventilation, especially given the long term field performance of HVAC systems and controls.

Figure 3. Should Windows Open?

No	**Yes**
Avoid outdoor pollution	Dilute indoor pollution – HVAC
	Dilute indoor pollution – materials/ activities diffuse
Avoid outdoor humidity	indoor humidity build up
Avoid outdoor noise (traffic, HVAC, mowers)	Connect to nature – air, sounds
Well designed/maintained HVAC provides control	Increase local ventilation rates w/o heat recovery
Avoid rain penetration	Increase local thermal control in cool periods
	Design windows to shed rain

The design implications for increasing daylight, view and natural ventilation are first to increase surface area with thinner floor plates, and second to resolve glare, overheating, heat loss, and rain penetration through appropriate enclosure design. In some respects, sustainable, healthy buildings have many of the characteristics of sustainable, healthy humans – they are physically fit rather than obese (thin floor plans, finger plans and courtyard buildings); they have circulatory systems that take the heat from the core out to the surface (eg. air flow windows); they absorb sunlight and breathe fresh air. At the same time, sustainable buildings are designed to reduce climate stresses – rain, cold and hot temperatures, diurnal temperature swings, excessive sun, freeze-thaw – with completely regional design solutions.

Guidelines for Sustainable Building Massing and Enclosure for Health

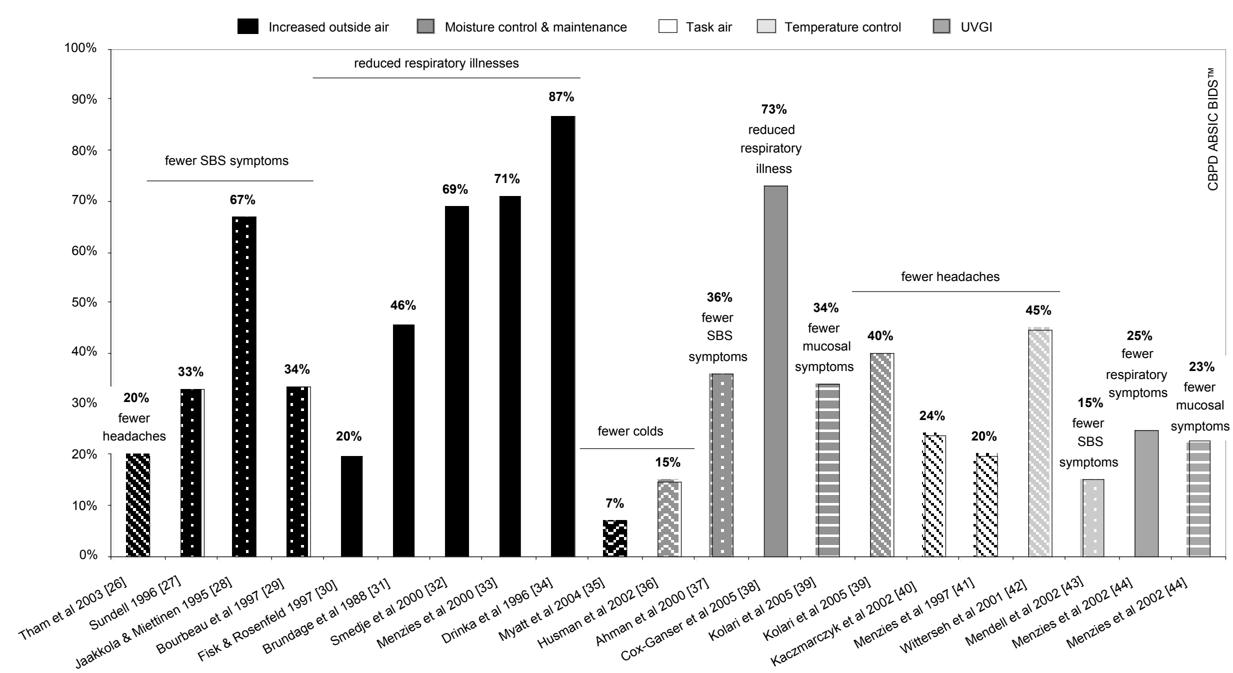
- Design for daylighting without glare to support visual acuity, reduce headaches
- Design for natural ventilation without drafts and rain penetration to reduce respiratory/flu symptoms
- Engineer thermal load balancing to eliminate radiant asymmetry - arthritis, circulatory disorders,
- Design for passive solar heating where climate appropriate for thermal comfort and UV benefits
- Design enclosure integrity to eliminate mold affecting SBS, respiratory/allergy and asthma

Sustainable HVAC and Health

The design of heating, ventilation and air conditioning systems for human health are based on at least three improvements in individual occupant conditions: increased outside air rates and filtration; improved moisture/humidity control; and improved thermal comfort control.

Healthy, sustainable air, for example, is dependent on a commitment to improving the quality and quantity of outside air. Increasing outside ventilation rates has substantial research justification: a doubling or tripling of code requirements for outside air measurably reduces headaches, colds, flus, nasal symptoms, coughs, and SBS symptoms [26-35]. This may be achieved by maximizing natural ventilation with mixed-mode HVAC systems, and/or designing the HVAC system with separate ventilation air and thermal conditioning systems (thermal conditioning can be water or air based). To ensure ventilation effectiveness, the ventilation system must be designed to provide air to the individual with task air systems with some level of individual control to address local pollutant buildup. At the same time, a healthy HVAC system will guarantee pollution source control through design configuration and maintenance and for effective filtration. Beyond the studies of natural ventilation/mixed mode conditioning previously discussed, the CBPD has identified seven international case studies demonstrating that high performance ventilation strategies reduce respiratory illnesses including asthma and allergies by 10-90%, as well as ten studies that demonstrate reductions in SBS, headaches, flus and colds (see figure 4). Specifically, the critical HVAC improvements are increasing outside air rates, mold/moisture control, air stream management and filtration. In addition to health benefits, thirteen studies also suggest individual productivity gains of 1.7-11% due to high performance ventilation strategies, with a small energy penalty for increasing outside air rates with heat recovery, or 50-80% energy savings for natural ventilation combined with mixed mode conditioning [25].

Figure 4. Health Benefits of High Performance HVAC [26-44]



In addition to providing healthy breathing air, it is critical for the HVAC system to provide individual thermal controls. While a majority of laboratory and field experiments in this arena relate to productivity and task performance, the CBPD has identified two international case studies that link thermal comfort to reduced headache and SBS symptoms [40, 41]. Clearly, extreme temperatures have measurable health consequences such as heat stroke and frost bite, but it is unclear whether long term exposure to moderately warm or cold thermal conditions have any health impacts. The health consequences of radiant asymmetry (the literal cold shoulder) and conductive losses through the feet to uninsulated floors, should be quantifiable, but no studies have been identified. However, the CBPD has identified 14 studies that link temperature control to individual productivity gains between 0.2-7%, while one study identified 15% percent savings in energy through task thermal conditioning, given consistent vacancy rates in office environments [45]. The challenges for HVAC design for thermal comfort are to: design for dynamic thermal zone sizes (changing use patterns); provide individual thermal controls (eg under floor air distribution system); design for building load balancing and radiant comfort; and finally, to engineer prototyped, robust systems that provide air quality and thermal comfort consistently as installed in the field, over time.

Sustainable HVAC for Health

- Increase outside air rates, through natural ventilation or HVAC with heat recovery – to reduce respiratory, allergy, asthma, colds, headaches, SBS
- Engineer ventilation effectiveness, including air path and filtration management – to reduce respiratory, throat and mucosal symptoms
- Engineer moisture/humidity management - to reduce mold affecting respiratory illnesses, colds, SBS
- Separate ventilation and thermal conditioning systems for individual thermal control – to reduce headaches and SBS symptoms

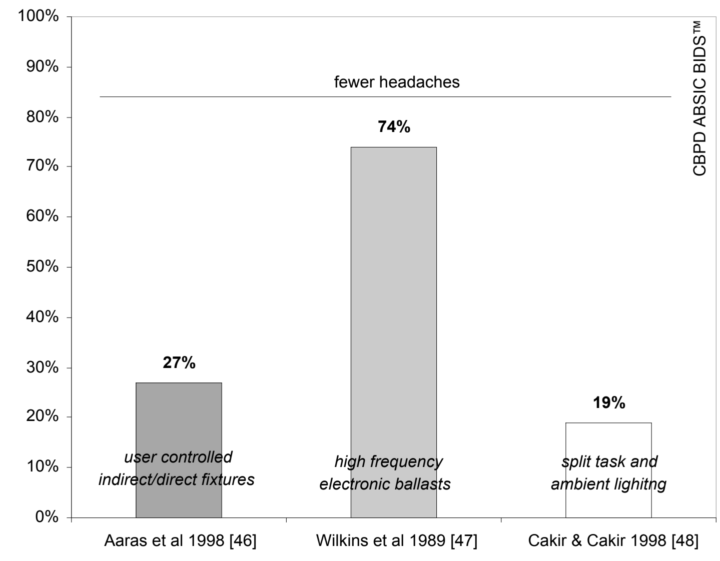
Sustainable Lighting and Health

Light levels and the control of glare and brightness contrast can dramatically impact performance at task. These variables can also impact health, with the most frequent symptoms being vision related headaches. In addition, the spectral distribution of the light source, as well as time of day variations in light, may have a measurable impact on circadian rhythms, as previously discussed. Finally, views that may be associated with daylight sources may have a measurable impact on depression, recovery rates, and SBS symptoms.

The CBPD argues for maximizing the use of daylight for both sustainability and health, so long as it can be provided without glare and excessive heat loss or heat gain. Daylight can provide the higher light levels needed for fine work, improve color rendition and sculptural definition, give the full spectrum and ultraviolet content that might be critical to circadian rhythms, and provide access to views of nature.

Electric lighting systems then have the responsibility to interface effectively with daylight to meet the needs of specific tasks, and provide the appropriate quantity and quality of light when daylight is not available. To this end, sustainable lighting is dependent on selecting the highest quality lighting quality fixtures, lamps, ballasts, reflectors, lenses and controls to light each specific task or task surface. These actions can also have health benefits. For example, replacing magnetic ballasts, with both audible buzzing and PCBs, with electronic ballasts in fluorescent lamps has resulted in a 74% reduction in the incidence of headaches in a study by Wilkins et al [47]. The separation of task and ambient lighting, to enable lower overall ambient light levels at 20-30 fc (supportive of computer work and face to face discussions) to be augmented by higher task light levels at 50-100fc (for fine print work), has resulted in 19% reduction in headaches in a study by Cakir and Cakir [48]. A third study revealed the benefits of reducing direct and reflected glare and shadowing that can occur with direct 'downlighting' from the ceiling: a 27% reduction in headaches resulting from a shift to indirect/direct lighting [46].

Figure 5. Health Benefits of High Performance Lighting [46-48]



In addition to these three international case studies that demonstrate that improved lighting design reduces headache symptoms, the CBPD has identified twelve international case studies that indicate that improved lighting design increases individual productivity between 0.7-23% while reducing annual energy loads by 27-88% [49].

Guidelines for Sustainable Lighting for Health

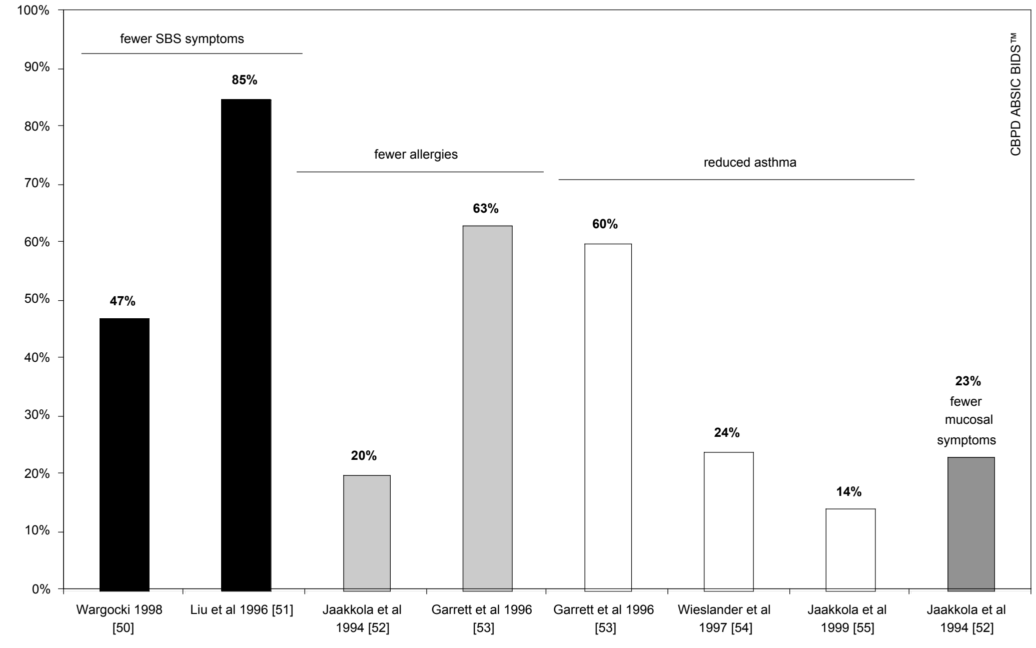
- Design for daylighting without glare to support visual acuity, color rendition, circadian rhythms, view content – reduced length of stay, headaches
- Specify high performance fixtures for maximum lumens/watt, reduced glare, shadowing and noise - reduce headaches
- Separate ambient and task lighting delivery to match light levels to task, provide control

Sustainable Interior Systems and Health: materials and ergonomics

Among a range of interior design decisions that affect sustainability and productivity, at least two design decisions also have measurable health impacts – material selection and the ergonomics of furniture and space layout.

Interior material selection is critical in relation to thermal performance, air quality (outgassing), toxicity in fires, cancer causing fibers, and mold growth, which in turn impact respiratory and digestive systems, eyes and skin. The CBPD has identified six studies linking materials selection to health outcomes including SBS, mucosal irritation, allergies and asthma (see figure 6). While sustainable design depends on the use of materials and assemblies that support healthy indoor environments, it also mandates the selection of materials with low embodied and transportation energy, since these environmental costs carry secondary health concerns.

Figure 6. Health Benefits of High Quality Interior Materials [50-55]

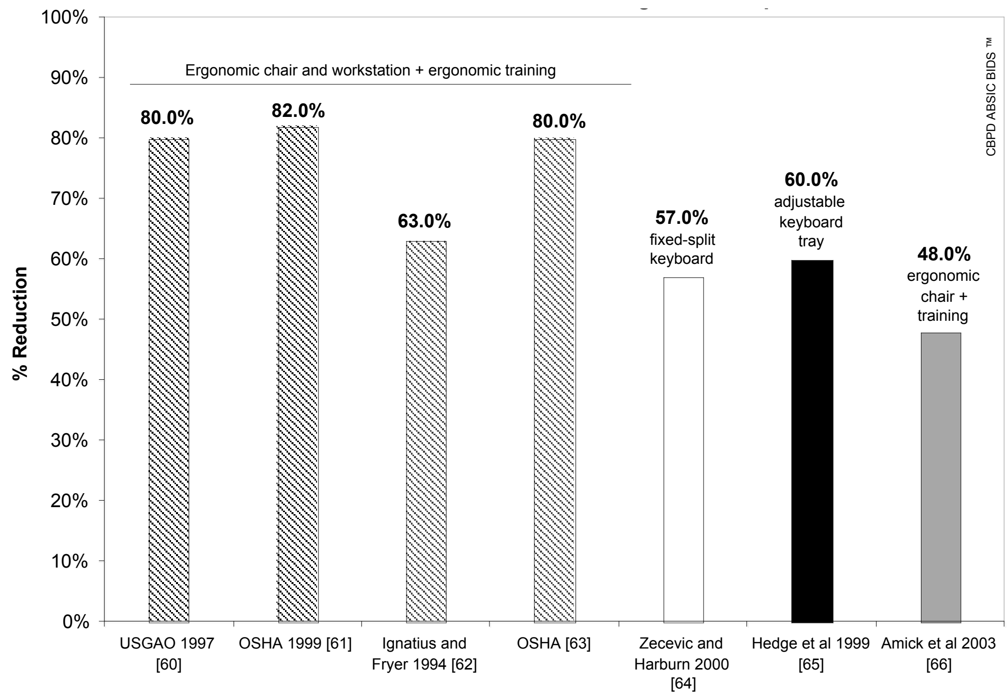


Guidelines for Sustainable Material Selection for Health

- Specify materials that do not irritate the skin with contact to avoid dermatological conditions
- Specify materials that do not outgas toxins to avoid respiratory/allergy and asthma
- Specify materials that do not degenerate into respirable fibers or emit radon to avoid cancers
- Specify materials that are not fire hazards causing respiratory illness or death
- Specify materials that do not foster mold or mildew leading to respiratory symptoms
- Specify materials with low embodied energy and low transportation costs to reduce outdoor air pollution

In addition to indoor surface materials, design decisionmakers must address the anthropometric and ergonomic needs of building occupants. Given the growing preponderance of computer-based work today, work surfaces, chairs, keyboards and mouse design must be ergonomically designed to reduce musculoskeletal disorders (MSD). According to a Washington State study, 1.7 to 3.2% of MSD complaints result in medical costs averaging $22,000 per affected occupant, and in many cases permanent consequences for the employee [56]. The CBPD has identified 7 international case studies that demonstrate that ergonomic workstations reduce MSD symptoms between 48 – 84% (figure 7). Ergonomic design goes beyond anthropometric concerns, however, to also address building layout and densities that support human health and productivity. Seneviratne and Phoon [57] identified over 40% reductions in nose, throat and mouth symptoms with greater workspace and improved maintenance. Jaakkola and Heinonen [58] identified a 35% lower rate of colds among occupants of individual offices, compared to those in shared offices. Hendrich et al [59] identified a 70% reduction in medication errors and a 60% reduction in patient falls through the design of acuity adaptable hospital rooms.

Figure 7. Musculoskeletal Disorder Reductions due to Ergonomic Improvements [60-66]



The most substantive body of research, as captured in the work of John Templer [67], may be the effective design of stairs, ramps, curbs and surfaces to reduce the frequency of falls, with measurable health consequences. The most rapidly emerging body of research may be related to the infections transferred by contact with door handles, faucets, even elevator buttons, and the importance of hands-free design and frequent hand washing. Each of these studies emphasizes the importance of space layout, finishes and furnishings to human health.

Guidelines for Sustainable Interior Design and Furnishings for Health

- Specify furniture ergonomics to reduce musculoskeletal disorders (MSD)
- Design spatial layout/density to reduce transmission of contagious illnesses (flus, colds)
- Design spatial layout to reduce falls, tripping
- Design layout and specify surfaces to reduce infections transferred by contact with hands free design

Sustainable Maintenance and Operations and Health

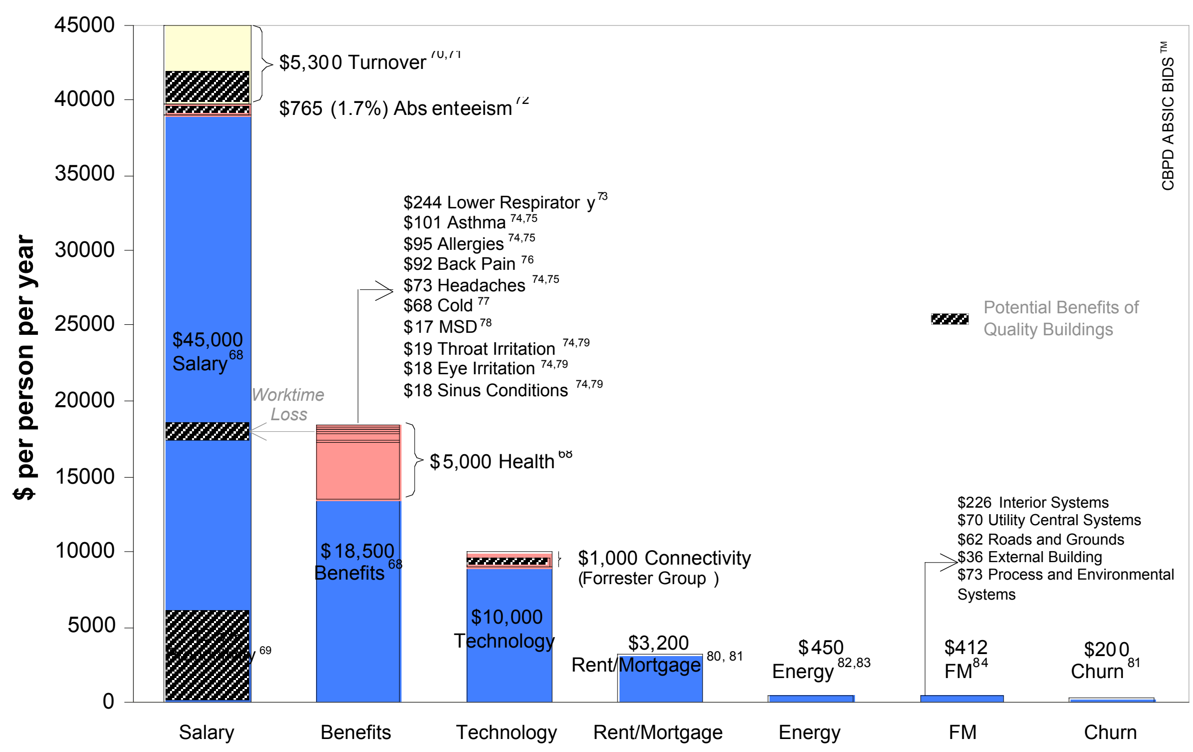
Needless to say, each of these design decisions will become obsolete if there is no commitment to long-term maintenance and operational standards. The building enclosure, HVAC and lighting systems must be continuously commissioned to maintain the healthy conditions intended. Standing water, dampness and mold must be prevented. Occupant densities must be managed, and furniture and finishes must continue to meet the health standards set.

In addition, human activities in buildings and the products they bring in must also be selected for health. Art supplies, cleaning supplies, plants, fertilizers and herbicides must all be environmentally benign. In addition, the food and water quality should be monitored for health, including guidelines for vending machines. Waste should also be effectively managed since it is a natural breeding ground for roaches, rodents and other pests. While this research team has not evaluated the studies that may link poor maintenance and operation practices to health concerns, it is clear that any degradation in as-built performance will result in health consequences equally serious as those of poor design, engineering and construction.

Calculating the Life Cycle Benefits of Sustainable Design and Health

The work of the faculty, researchers and graduate students of the Center for Building Performance and Diagnostics at Carnegie Mellon and the Advanced Building Systems Integration Consortium extends beyond the pursuit of building case studies that link the quality of buildings to productivity, health and life cycle sustainability. The development of the BIDS™ tool has necessitated the identification of "soft" and hard life cycle costs in building ownership in order to calculate the return on investment of high performance building systems (see http://cbpd.arc.cmu.edu/ebids). Figure 8 helps to reveal the diverse building-related costs of doing business in US offices, including salaries and health benefits, technological and spatial churn, rent, energy and maintenance costs. This cost is normalized in dollars per person per year, rather than cost per square foot, since the employee represents both the greatest cost and the greatest asset to an organization.

Figure 8. Improving the Quality of the Built Environment will Reduce the Life Cycle Costs of Business [68-84]



According to independent non-profit organizations, human resource research firms, and the U.S. government, the average employer cost for health insurance was approximately $5,000 per employee per year in 2003 [85-89]. The CBPD has been able to identify the cost of several specific health conditions and illnesses that can be linked to the quality of the indoor environment, including colds, headaches, respiratory illnesses, musculoskeletal disorders, back pain (see figure 8), which account for roughly $750 of the $5000 annually spent per employee, or 14% of all annual health insurance expenditures. These direct costs for medical attention and pharmaceuticals would be multiplied with the indirect costs of reduced speed and accuracy on task, lost work time and absenteeism, among other secondary consequences of health concerns.

While the focus of the BIDS™ effort to date has been to improve the quality of workplaces in office buildings, there is growing interest in identifying case studies for other facility types, such as schools and hospitals. This inclusion broadens the opportunity to find case studies linking building quality to performance outcome, but requires research to customize the life-cycle factors and calculations to that building type, and to develop new design recommendations that might emerge from these data sets.

Example Measures of Cost-Benefit Performance for Different Building Types

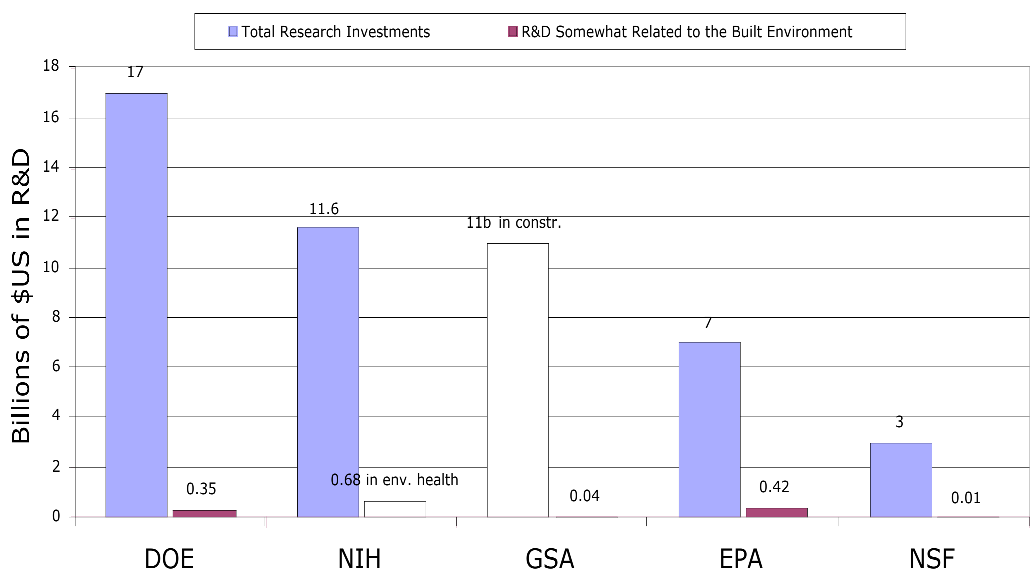
Offices	Schools	Hospitals
O&M, Energy & Water	O&M, Energy & Water	O&M, Energy & Water
Worker Health	Teacher Health	Length of Stay/Recovery Rates
	Student Health	Nosocomial Infections
		Patient Falls
		Staff Health
Attraction-Retention	Teacher Turnover	Staff Turnover
Individual Productivity	Student Test Scores	
	College Placement	
Absenteeism/Presenteeism	Absenteeism/Presenteeism	Absenteeism/Presenteeism
Organizational Productivity		Bed Vacancies
Market Share/ Customer	Drop-out rates	Cost/Bed
Speed to Market	No Child Left Behind	Profit/Bed
Waste Cost/Benefits	Waste Cost/Benefits	Waste Cost/Benefits
Litigation/Insurance/Tax		
SBS		Medication Errors

For example, the calculation of life cycle benefits of better design, engineering and management of hospitals would include variables such as: the average length of stay per illness, averaged at 4.6 days per patient in US hospitals [90]; average cost of hospital stay, set at $1217 per day in US hospitals [91]]; patient reinfection rates, estimated at 2.16/10,000 patient days in US hospitals [92]; average of cost of these nosocomial infections, estimated at $27,000 plus 12 day increase in hospital stay [93]]; and the average cost of nurse turnover, at $13,800 per nurse per year [94-96]. The magnitude of these costs would clearly justify significant investment and reinvestment in the quality of buildings to ensure long-term health and productivity.

Health and the Built Environment: A major research Mandate

Sustainability is in truth all about health. Energy/material extraction and use and atmospheric, water and land pollution are as significantly health-related issues as they are environmental conservation issues. Certainly the design and maintenance of building enclosures, HVAC, lighting, and interior systems are directly linked to our short and long term health, as the evidence collected in this paper has begun to prove. Human health in the built environment is one of the most critically needed research efforts, requiring both extensive experimental and field research efforts. Controlled laboratory experiments need to be carried out simultaneously with experiments in the field – to map chains of consequence, and identify possibly building related causes for respiratory, digestive, circadian, musculo-skeletal, circulatory, and nervous system illnesses, as well as other health related concerns. Yet in the United States, at least, there is remarkably little federal investment in defining and valuing healthy buildings and communities (see figure 9).

Figure 9. Yet Marginal Research Investments in the Built Environment [97]



One cannot overstress the importance of defining key national and international research directions for addressing the impact of the built environment on health. Bringing together emerging knowledge about the importance of land use, building enclosure, HVAC, lighting and interior design decisions, with the life cycle justifications to ensure their implementation, is critically needed. Sustainable buildings and communities have the potential to deliver the highest quality air, thermal control, light, ergonomics and acoustic quality, as well as regionally appropriate access to the natural environment, which are integral to human health.

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