BUILDING INVESTMENT DECISION SUPPORT (BIDS™)

Cost-Benefit Tool to Promote High Performance Components, Flexible Infrastructures and Systems Integration for Sustainable Commercial Buildings and Productive Organizations

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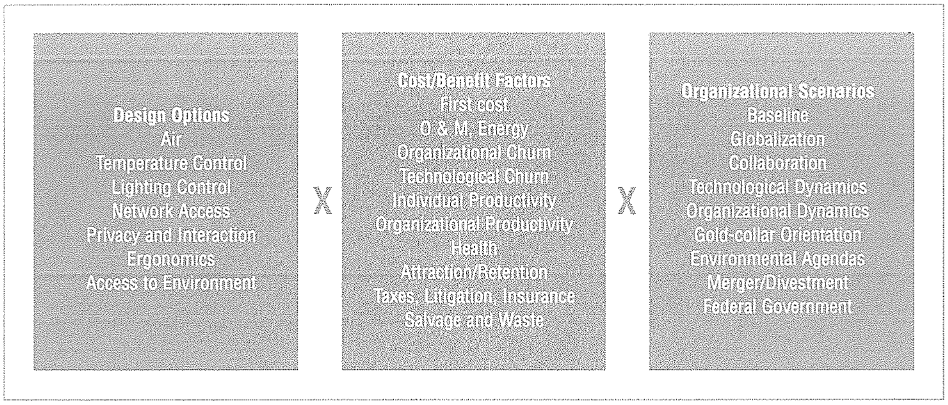


Figure 1. The Three Dimensions of the CBPD BIDS™/ EVA Matrix

1. Move beyond broad definitions of sustainability to justify high performance materials and assemblies.

Investment in high-performance, sustainable building design and technologies is limited by first-cost decision-making. In our collective enthusiasm to define and promote sustainability, we may be making two fundamental errors: first, broad "motherhood" definitions of sustainability, and second, arguments that green design need not cost more.

Environmental designers often argue for broad sustainability objectives without further detail, as expressed in the AIA/UIA declaration of Interdependence for a Sustainable Future "Sustainable design integrates consideration of resource and energy efficiency, healthy buildings, ecologically and socially sensitive land-use, and an aesthetic sensitivity that inspires, affirms and ennobles." However, investors and clients will need to understand the specific quality differences of sustainable design alternatives—component by component—if they are to move beyond least-first-cost decisionmaking. Imagine selling only "mobility" with cars ranging from $10,000 to $30,000. Every 'investor' knows component by component the quality differences in the two cars, including life cycle benefits, and typically invests in the higher cost product to purchase performance qualities. Imagine selling only "computational capability" with laptops ranging from $1000 to $3000. Again, the computing industry has made quality differences in even the most hidden infrastructures in laptops evident to the customer, leading to higher quality purchases. The genius of LEED™ certification from the U.S. Green Building Council[2] is that it defines sustainability in 69 more defined goals, giving the client the opportunity to qualify a greater investment of expertise or capital in their buildings.

While promoting either broad or detailed sustainability goals, many sustainable building designers will simultaneously argue that 'green' design should not cost more. This has led to a number of national studies on the cost of green, from Greg Kats' "Cost and Benefits of Green Buildings"[3] to GSA's "LEED® Cost Study"[4]. These studies have demonstrated that modest 2-4 percent cost increases can achieve Silver and Gold level LEED certification, ensuring improvements for sustainability with short term cost paybacks. While invaluable arguments for introducing sustainability, these modest cost increases are locking architects and engineers out of true quality improvements in a wide range of building materials, components and systems that are critical to ensuring: indoor air quality, thermal control, lighting control, network access, privacy and interaction, ergonomics, and access to the natural environment. The cost of a high quality light fixture, for example, one with the most energy effective T-5 lamp, continuous dimming and daylight responsive ballast, high performance reflector and lens, and potentially even separate ambient uplighting and task downlight, might demand the 3 to 1 ratio of quality and cost typical in other industries, in order to replace the least cost components that are typically installed. It is imperative that life-cycle data sets and tools be developed to establish the cost-benefits of high performance building technologies–component by component. The Advanced Building Systems Integration Consortium (ABSIC), a consortium of industries and federal agencies, and the Center for Building Performance and Diagnostics (CBPD) continues a ten-year effort to define high-performance buildings to promote each component and system innovation that will enhance the quality of the individual workplace (figure 2).

CBPD/ABSIC Design Guidelines for High Performance Buildings 2004

Guidelines for High Performance Enclosure Systems
1. Maximize individual access to the natural environment
2. Maximize daylighting for task and ambient lighting
3. Maximize natural ventilation with mixed-mode conditioning
4. Minimize enclosure heat loss/heat gain
5. Design solar heat and glare control
6. Engineer load balancing and mean radiant temperature control
7. Engineer passive and active solar heating, cooling and power
8. Maximize enclosure integrity and material sustainability
9. Pursue innovative systems integration for environmental quality, resource conservation and health

Guidelines for High Performance HVAC
for thermal and air quality, resource conservation & environmental health.
1. Separate ventilation systems from thermal conditioning
2. Design for natural ventilation with mixed-mode conditioning
3. Provide task conditioning and individual control
4. Design for continuous change with plug and play HVAC & controls
5. Design architecture 'unplugged' for maximum efficiency and passive
6. Engineer load balancing
7. Engineer energy and material effective HVAC systems with 'energy cascades'
8. Create distributed, communicating, modifiable automation systems
9. Pursue innovative systems integration for environmental quality, resource conservation and health

Guidelines for High Performance Lighting
1. Provide Daylighting as a dominant light source
2. Separate task lighting from ambient lighting or design relocatable task-ambient systems.
3. Introduce indirect-direct lighting to support spatial dynamics without shadowing.
4. Maximize lighting quality with high performance luminaires.
5. Provide for reconfigurability with plug-and-play fixtures.
6. Design for continuous change in lighting zone size and advanced controls
7. Pursue innovative systems integration for environmental quality, resource conservation and health

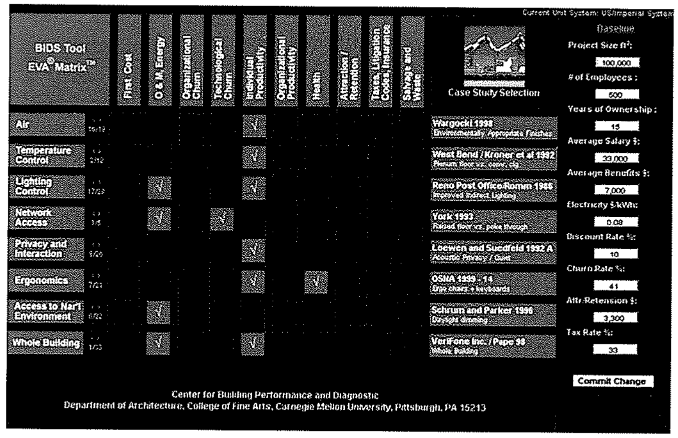
Guidelines for High Performance Connectivity
Networks for spatial flexibility, technological adaptability, and resource conservation.
1. Engineer independent plug-and-play networks—data/voice, power, security, and environmental services— with central communication
2. Design distributed cores for accessible, modifiable vertical distribution
3. Design distributed satellite closets with plug-and-play interfaces
4. Resolve integrated, reconfigurable plenum systems – ceiling or floor
5. Ensure user accessible, modifiable grid and nodes of services for connectivity
6. Create wiring harnesses for data/voice, power, security and environment
7. Select terminal units that provide all services—data, power, voice, security, environment—in reconfigurable boxes for just-in-time modifications
8. Create robust monitoring and individualized controls

Guidelines for High Performance Interior Systems
1. Design neighborhood clarity & shared spaces with flexibility
2. Design layers of ownership, multiple work environments
3. Ensure ergonomics/ functional support for shared work processes
4. Ensure ergonomics/functional support for individual work processes
5. Design "layers of closure," privacy and acoustic control
6. Design "layers of mobility" for workstations and workgroups
7. Provide levels of personalization
8. Ensure environmental infrastructure to support changing densities/ closure
9. Ensure technical infrastructure to support changing densities/ closure
10. Select interior system/components for material & energy conservation
11. Select healthy, maintainable interior components
12. Design for access to the natural environment

Design Process Changes for High Performance Buildings
? Involve full design team from the outset to ensure integrated design
? Develop Prototyped, Roll-out, Plug and Play Delivery of: Air Quality, Thermal, Connectivity, Light, Interior Spaces
? Shift from Design-Build to Manufacture-Install for Life Cycle Value
? Shift to JIT Purchasing of Infrastructures for quality with cost control
? Establish Flexible Infrastructures for Dynamic Organizations

Figure 2. Guidelines to Improve the Quality of the Individual Workplace

The BIDS™ cost benefit analysis decision support tool



The Benefits of High Performance Buildings

1. **First Cost/Mortgage Savings through Quality Packages**
   Integrated System Savings over Individual Components
   Quality and Modularity with JIT Purchasing over Redundancy
2. **Facilities Management Cost Savings**
   Maintenance, Repair, Energy, Water, other Utilities, Cost of Discomfort, Failure costs, employee retention and training
3. **Individual Productivity Cost Savings:**
   (skill based, rule based, knowledge based jobs)
   Speed and Accuracy, Effectiveness, Creativity, Motivation, Absenteeism
4. **Organizational Productivity Cost Savings:**
   Profit, Time to Market, Customer Attraction and Retention, Recognition and Publicity, Continuous Work Flow, Real Estate Effectiveness, Team/Multi-disciplinary Creativity
5. **Attraction/ Retention or Turnover Cost Savings:**
   Time and Cost to Attract, Quality Attracted, Training Costs, Retention Rates
6. **Tax/Code/Insurance/ Litigation Cost-Savings**
   Utility & Tax Incentives, Tax Depreciation, Code Compliance, Insurance & Litigation Costs
7. **Health Cost Savings:**
   Workman's Compensation, Medical Insurance Costs, Health Litigation Costs, Environmental Evaluation & Remediation, Lost Work Time
8. **Spatial Renewability Cost Savings**
   Organizational Churn
   Labor and material costs for reconfiguring workstations and workgroups, hvac/lighting/networking system modification costs, occupant down-time
9. **Technological Renewability Cost Savings:**
   Technological Churn
   Networking: data/power/voice change, hardware/software change, training/mentoring costs, organizational/workspace and environmental/conditioning response costs
10. **Salvage/Waste Cost Savings**
    Organizational, Technological, Environmental Modifications, Activity related waste, Aging & Wear, Obsolescence, Salvage Value

Figure 3. The Broader Cost of Ownership

2. To justify high performance building components and systems, Understand the Cost of Ownership

In order to promote investment in sustainable, high quality buildings, it will be critical to prove to the client that the real cost of doing business is realized over time, not in first construction costs. Careful bookkeeping will reveal that "cheap" buildings and infrastructures, and "cheap" building delivery processes, result in major costs over time—energy costs, waste and renewal costs, productivity and health costs.

Moving beyond the "mantra" of individual productivity, the CBPD team has been researching the broader range of workplace-related expenses that are carried annually by organizations—from energy and facility management costs to churn and health and litigation costs. Most professionals know about the comparative advantage of productivity at $200/sq.ft./year, rent at $20/sq.ft./year and energy at $2/sq.ft./year. Yet productivity in the white collar workplace is hard to define and hard to measure, such that arguments for high performance, sustainable buildings may be more convincingly made with other annual expenses carried by the organization. The Carnegie Mellon BIDS™ research team has identified a list of ten cost-benefit areas where annual organizational investment is significant and could be reduced through a commitment to higher quality buildings (figure 3).

Figure 4. Cost of Doing Business

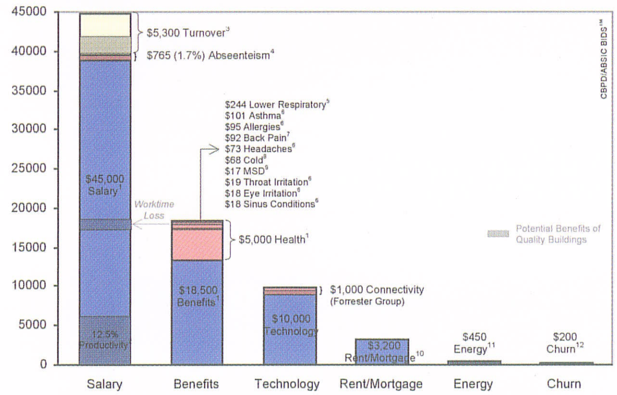


Figure 4 illustrates the strength of the data that the Center for Building Performance at Carnegie Mellon has been able to assemble on the cost of doing business that might be critically linked to the quality and sustainability of building components. The following sections will outline the baseline data for five of the ten cost-benefit arenas that the BIDS™ team continues to research, data that should help professionals "build the life cycle case" for high performance buildings.

2.1 Facilities Management Cost Savings

Maintenance, Repair, Energy, Water, Other Utilities, Cost of Discomfort, Employee Retention and Training, Failure Costs.

High performance buildings have the potential to generate significant operational cost savings, ranging from energy and other utility efficiencies, to facility management effectiveness, to the potential to reduce failure costs and measurable lost work time due to system failures. 25–50 percent energy savings, for example, can be achieved in most existing buildings and in sustainable approaches to new and construction. Since energy costs are often well known by a building owner, substantial recommendations for energy efficient innovations are often seriously considered if payback is less than 1–3 years. Beyond this time frame, however, few decision-makers believe in the predictions of the cost of energy, or that they will still own the building and be accruing savings from the innovation. With state and utility incentives to reduce peak power demands, and corporate investments to ensure power reliability in a brown-out, additional financial resources are available to invest in high performance building materials, components and integrated systems.

Maintenance and repair cost savings are less successful at promoting higher quality building systems, because there are very incomplete records on causes of maintenance and repair costs (including manpower) or the benefits of different design/engineering solutions. At present, energy use is typically 1–2 percent of current plant value, and facility management/ maintenance and repair costs are typically 2–4 percent of current plant value indicating the importance of pinpointing the costs of discomfort and failure due to inadequate investments.[5]

2.2 Individual Productivity Cost Savings:

Speed and Accuracy, Effectiveness, Creativity, Motivation, Absenteeism

Since a majority of the cost of doing business is for salaries (as much as 60 percent), any innovation that will clearly increase productivity even by a small percent will quickly payback investments in quality products and systems. Excluding benefits, the average annual compensation or salary for workers is $45,000 in the private sector and $50,000 in the public sector, given 2002 Bureau of Labor Statistics.[6] Even 1 percent of productivity savings would yield over $4,500 per employee per year to justify improved investment in the quality of their workplace. Adrian Leaman in England estimates the potential impact for buildings on overall productivity as +12.5 percent (improved performance) and -17 percent (hampered performance), for an overall 30 percent change in worker performance in the best and worst buildings[7].

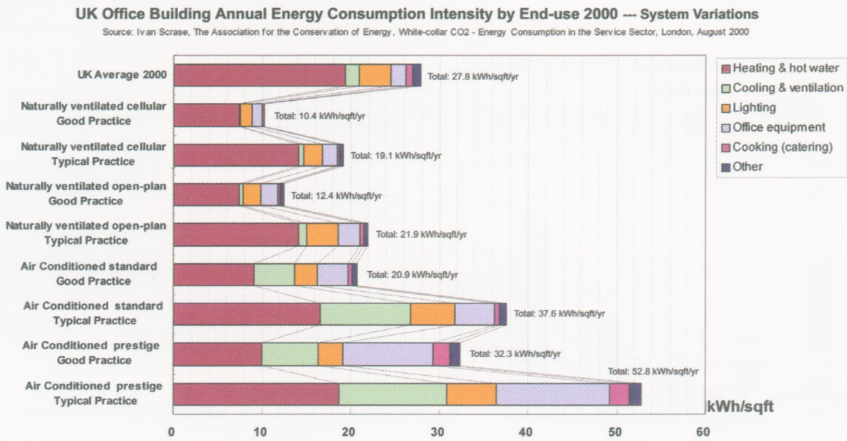


Figure 5. Annnual Energy Consumption Intensity of Office Building Types in U.K.

However, measuring productivity of the knowledge worker is very difficult, and must be studied differently for skill-based, rule-based and knowledge-based jobs.[8] While speed and accuracy may be easily tracked in skilled/manual jobs or even rule-based jobs such as call centers, knowledge-based work requires different measure-ment techniques to capture effectiveness at multiple tasks—both individual and collaborative. Creativity, motivation and focused attention, communication and collaborative output, as well as absenteeism and job impairment are meaningful but difficult indices to measure.

The two most readily available indices to evaluate investments in quality buildings are absenteeism (or unused sick days) and self assessment of productivity. In reference to absenteeism, the 2002 United States department of Labor's Current Population Survey[9] identified that private sector employees in the United States missed an average of 1.7 percent of scheduled work time. Given average weekly hours and salaries reported in the National Compen-sation Survey,[10] this amounts to 35 hours of missed work at a total cost of $756 annually. Absenteeism among public sector employees was slightly greater, at 2.2 percent or 42 hours, with an annual cost of $1,100. An additional indicator that could be explored is observed downtime for workplace modifications, complaints, and interruptions.

Some organizations have ongoing measures for worker performance that might include speed and accuracy (for example call center shipments), patents or products brought to market, and customer satisfaction. In controlled studies of white collar productivity, a battery of "knowledge based" tests, including simple, moderate and complex tasks, are used to evaluate the impact of workplace attributes on performance. These tests could include: seven number recall, phone book look-up speed, typing speed and accuracy, calculations, sentence completion, paragraph memorization, and creative thinking tests.

2.3 Attraction/ Retention or Turnover Cost Savings:

Time and Cost to Attract, Quality Attracted, Training Costs, Retention Rates

Another aspect of the productivity cost-benefit equation is the ability to attract and keep the best workers, the time needed for training, and the commitment of those workers to their work, including unpaid overtime. Average turnover rates for private professional positions is 20.3 percent with 6.8% rates for government positions.[11] A 2000 study by Jac Fitz-Enz identified four costs associated with employee turnover: termination, vacancy, replacement, and productivity loss.[12] The costs are calculated as follows:

Total cost of turnover for one position

Termination	$ 1,000
Replacement	$ 9,000
Productivity	$ 15,875 (3 months baseline salary and benefits)
Total - with 20.3% turnover rate	**$ 25,875** $ 5,300 per employee per year

Table 1. Total Cost of Turnover

1. **Termination**–Staff time to process the departing employee. It includes collecting badges, keys and company equipment, removing the departing employee from company payrolls and security lists, and processing any benefits extension programs. The typical cost of termination is $1,000 to $1,500 in staff time.

2. **Vacancy**–Assuming that all employees add value to the company or they would not be employed, a loss of revenue is incurred for every day a position is vacant. The cost of vacancy is the company revenue per employee per day multiplied by the number of days a position is vacant minus the cost of pay and benefits for the employee for those days.

3. **Replacement**–Cost of recruiting and inter-viewing candidates and processing and orientation for a new employee. The average cost is $1,100 for a non-exempt position, which is usually hourly waged and paid overtime, and $9,000 for a exempt position which is usually a salaried professional with no paid overtime.

4. **Productivity loss**–Due to a "learning curve," a new employee is rarely as productive as a departing one, so there is a decline in performance for some period of time until the new hire's productivity matches that of the former employee. The absolute minimum loss is the equivalent of three months' pay and benefits. For professional positions, this cost is likely to be much higher—up to one year's pay and benefits.

With average private sector turnover rates over 20%, the $5,000 lost per employee each year to the inability to attract or retain employees is a significant "cost center" for employers. In arguing for high performance, sustainable work environ-ments, it will be critical to establish the link between attracting and retaining the best employees and the quality the physical, environmental and technological workplace.

2.4 Health Cost Savings:

Workman's Compensation, Medical Insurance Costs, Health Litigation Costs, Environmental Evaluation & Remediation, Lost Work Time

After salary, the second major annual cost of an employee is benefits, including medical and insurance costs, as well as workman's compensation. Based on nine health insurance costs reported in five references, the BIDS™ baseline for employer health insurance cost is set at $5,000 per employee per year. Measured reductions in these costs would justify investment in better quality environments.

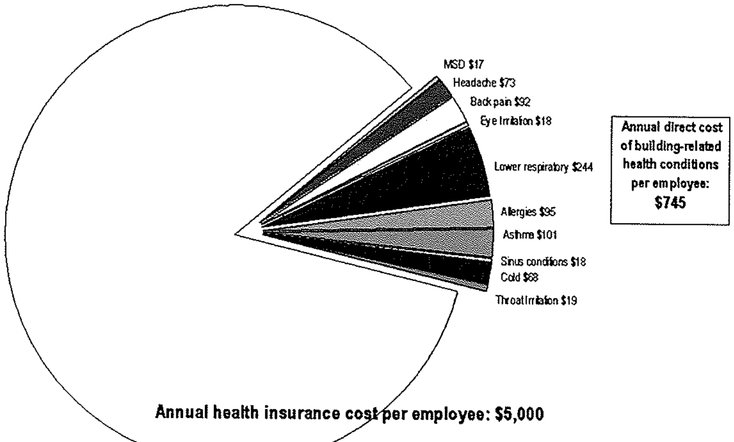


Figure 6. Annual Health Cost per Employee

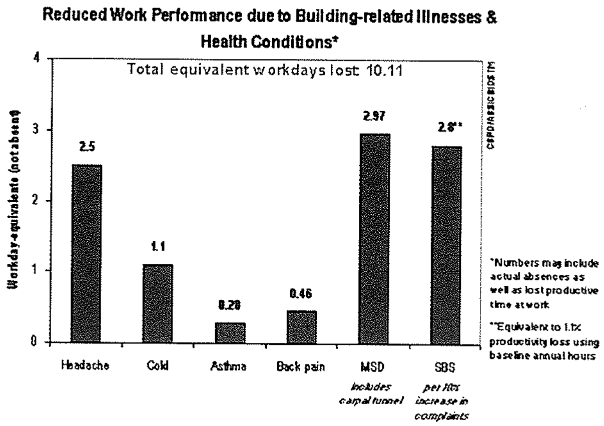


Figure 7. Lost Workdays Due to Building Related Illnesses

Given the CMU research to date, treatment for illnesses and health conditions that may be directly influenced by the indoor environment is costing employers $745 per employee annually, approximately 15 percent of all annual health insurance expenditures. Health conditions and illnesses that have been linked to the indoor environment include colds, headaches, respiratory illnesses, musculoskeletal disorders, back pain, and symptoms of Sick Building Syndrome (SBS).

The most easily identified health cost-savings linked to the quality of buildings are within workman's compensation, especially as related to muscular skeletal disorders (MSD). In the State of Washington, workers compensation claims for muscular skeletal disorders average over 43,000 per year with an average 1.84 workdays lost per employee.[13] Given average claim rates of 3.6 percent per workforce and median MSD cost of $470, the average MSD cost per employee per year is $17, which can be substantially offset (over 80 percent) through ergonomic furniture and employee training. The annual cost of muscular skeletal disorders may be only 'the tip of the building related iceberg', since the annual workman's compensation costs per employee exceeds over $500 per year according to the Bureau of Labor Statistics data.[14]

Beyond direct medical costs, researchers in the medical and occupational health fields have begun to identify the indirect costs of these health conditions to employers. As shown in figure 7, the indirect cost of productivity losses due to illnesses and health conditions may be even more significant than the direct costs for medical treatment. Not revealed in days absent, the indirect costs for health conditions are reflected in reduced effectiveness on the job, such as when an employee comes to work with a cold or continues working with a headache. The BIDS™ team has identified indirect (productivity-related) costs of several illnesses that are influenced by the indoor environment, including equivalent workdays lost due to colds, respiratory illnesses, musculoskeletal disorders, and Sick Building Syndrome (SBS).

One of the most dramatic health-related costs may be tied to "sick building syndrome" mitigation, including the direct and indirect health costs of employees, field study costs, remediation costs, litigation costs, and building down-time costs. Due to the fact that the many serious SBS cases have been settled out of court, findings that would lead to improving the workplace have not translated into greater investments in high performance design/engineering solutions.

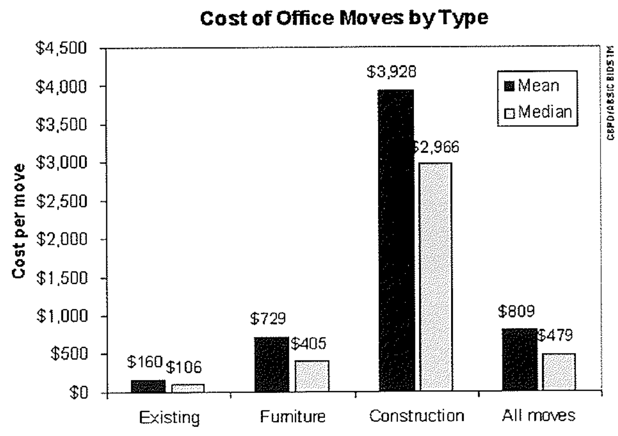


Figure 8. Cost of Office Moves by Type Based on IFMA Research Report 23, 2002

2.5 Spatial Renewability: Organizational Churn Cost Savings

Labor and material costs for reconfiguring workstations and workgroups, HVAC/Lighting/Networking System Modification Costs, Occupant Down-Time

There are significant cost-benefits to investing in renewable, quality building systems to reduce the cost of "churn". The International Facility Management Association (IFMA) has tracked churn rates for over a decade. From a survey of 291 companies in 2002, IFMA reports a mean churn rate of 41 percent for all types of facilties. IFMA classifies office moves in three categories: box moves, furniture moves, and construction moves. Given the diverse mix of types of moves in the 291 companies, the average cost per move was $809, while the median cost per move was $479[15]. These significant annual expenses are incurred to support the cost of: reconfiguring working groups and individual space; accommodating changes in functions, densities, and work hours; and accommodating rapid changes in technologies on the desktop.

Some organizations have been working to reduce space reconfiguration costs through universal footprints, shifting to "box moves" from one identical cubicle to another, especially in back offices. Other organizations are pursuing massive reconfigurations to support non-territorial offices, mobile workstations, micro workstations, and teaming spaces in response to organizational re-engineering. At the same time, occupant density, length of workday, and technology have dramatically increased in the workplace. As a result, system overload and failure costs are now accruing beyond the already significant costs of conventional churn. The extent of these organizational churn costs are not well documented, nor the benefits of investing in quality, "renewable" solutions, resulting in a lack of support for better life-cycle decision making.

3. BIDS™ — Linking quality building components to life cycle gains

Begun in 1999, the goal of the BIDS™ project at Carnegie Mellon University's School of Architecture has been to develop a cost-benefit analysis framework for advanced and innovative building systems and to incorporate these within a multimedia decision support tool. There have been four specific objectives set to achieve the goal:

1. The development of economic language and logic whereby intelligent workplace design can be thought of by the business investor as analogous to other emerging, strategically-central investments that have different operating life cycles (economic sustainability), competitive implications (workforce impacts), and payback periods (capital market valuation criteria).

2. The development of a cost-benefit analysis framework for evaluating various advanced and innovative building system options in relation to a range of cost-benefit or productivity studies, to be incorporated within a multi-media decision tool.

3. The determination of cost centers where the benefits of high-performance approaches will be significant and the expansion of a database relating quality indoor environments to major capital cost and benefit areas, including productivity, health, and operations costs.

4. The identification of laboratory and field case studies demonstrating the relationship of high-performance components, flexible infrastructures and systems integration to the range of cost-benefit or productivity indices.

Extensive review of the relevant literature to identify valuable case studies as well as related cost-benefit baseline data is a major part of this research project. The CMU BIDS™ team has been avidly pursuing case studies from around the world that link improved building environmental quality to life cycle cost-benefits. For each 1000 abstracts reviewed and 100 promising papers read, one case study with statisically significant data can be identified. With over five years of research attention, the BIDS™ tool now has over 150 case studies linking high performance building components and systems to life-cycle value.

4. Proof Sets in Hand

With the expansion of the case study database, the BIDS™ tool is beginning to have an adequate number of proofs to derive cross-sectional findings in relation to providing air, thermal control, lighting control, network access, and access to the natural environment for the individual workplace. With support from the Department of Energy, these cross-sectional findings enable us to convincingly argue for at least five critically important improvements in the quality of our buildings (http://cbpd.arc.cmu.edu/ebids).

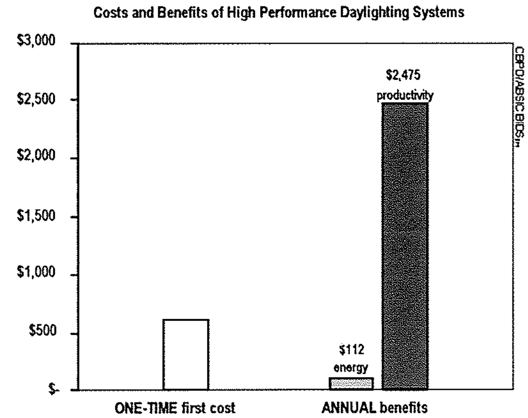


Figure 9. Cost and Benefits of Innovative Ligthing Systems (http://cbpd.arc.cmu.edu/ebids)

4.1 Access to the Natural Environment: Daylight and Natural Ventilation

Over 10 percent of all U.S. energy use is in lighting buildings, much of this during the daytime when daylight is abundant. Add to this the 6 percent of all United States energy use spent cooling buildings summer and winter, and you have a significant argument for the environmental benefits of windows for daylighting and natural ventilation. Given the dominant number of existing buildings—schools, hospitals, offices, manufacturing facilities—originally designed for effective daylighting and natural ventilation, the erosion of natural conditioning is a serious energy cost to the nation.

Effective daylighting can yield 10-60 percent reductions in annual lighting energy consumption, with average energy savings for introducing daylight dimming technologies in existing building at over 30 percent.[16] Emerging mixed-mode HVAC systems that interactively support natural ventilation and air conditioning are demonstrating 40-75 percent reductions in annual HVAC energy consumption for cooling. Moreover, design for access to the natural environment, including daylighting and natural ventilation strategies, has shown measurable gains for productivity and health in the workplace.[17] The United States needs to meet European and Scandinavian standards that ensure that every worker is within 7 meters of a window wall, for views, light and air. The effective use of natural conditioning with well designed windows, window controls, and mechanical and lighting system interfaces, promises to yield major energy efficiency gains of up to 5 percent of all United States energy use, reduce risk in power outages, as well as provide measurable health and quality of life gains.

Daylighting Pays!

Maximize the use of daylight without glare and provide daylight-responsive lighting controls to ensure 22-60 percent overall energy savings, 35-65% lighting energy savings, and 0.45-40 percent productivity gains, for ROIs over 185 percent.

Eleven case studies have shown that innovative daylighting systems can pay for themselves in less than one year due to energy and productivity benefits. The BIDS™ tool demonstrates that daylighting yields annual energy cost savings of $112 per employee (~$1.00 per square foot) and annual productivity gains of $2,475 per employee, for total savings of up to $2,587 per employee annually. At one-time first cost premium of $600 per employee (~$3 per square foot in new construction), the ROI for an investment in daylighting is over 185 percent.

These conclusions have been built on three case studies indicating an average 44 percent reduction in overall energy consumption; six case studies indicating 52 percent average lighting energy savings due to high performance daylighting systems; and five case studies demonstrating individual productivity benefits from daylighting, with an average improvement of 5.5 percent annually. Finally, one case study written by Heschong Mahone Group[18] identifies a 40 percent improvement in organizational productivity due to daylighting, reflected in the increased retail sales in 72 daylit "big box" stores as compared to 36 stores without skylight.

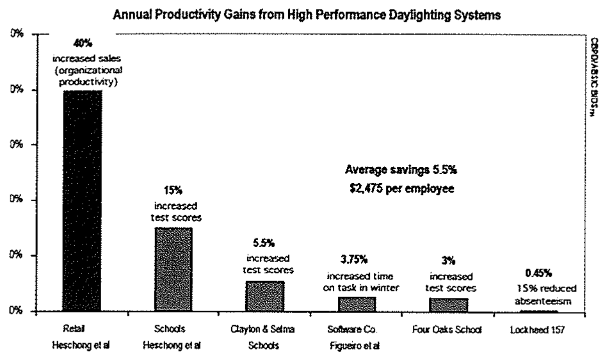


Figure 10. Productivity Benefits Associated with Daylighting (http://cbpd.arc.cmu.edu/ebids)

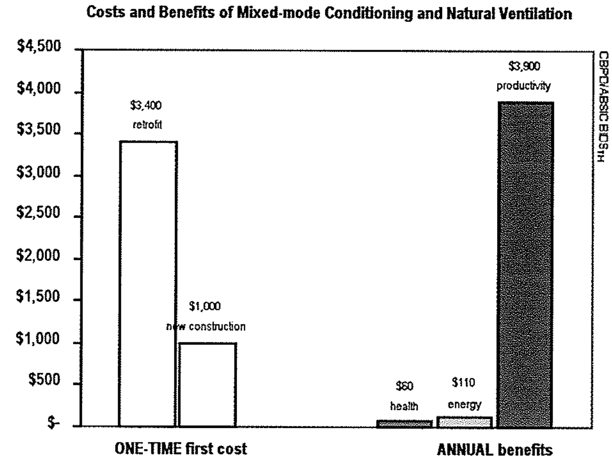


Figure 11. Cost and Benefits of Innovative Ligthing Systems (http://cbpd.arc.cmu.edu/ebids)

Natural Ventilation and Mixed Mode Conditioning Pays!

Replace or supplement mechanical ventilation with natural ventilation or mixed-mode conditioning to achieve 47-79 percent HVAC energy savings, 0.8-1.3 percent health cost savings, and 3-18 percent productivity gains, for an average ROI of at least 120 percent.

At the same time, eight case studies have shown that natural ventilation and mixed-mode systems can pay for themselves in less than one year due to energy and productivity benefits. The BIDS™ tool demonstrates that natural ventilation and mixed-mode systems yield annual energy cost savings of $110 per employee ($0.53 per square foot), health cost savings of $60 per employee, and annual productivity gains of $3,900 per employee, for a total savings of $4,070 per employee annually. With an estimated first cost premium of $1,000 per employee ($5 per square foot) in new construction and a documented first cost of $3,400 per employee ($17 per square foot) to modify an existing building, the average ROI for an investment in natural ventilation or mixed-mode conditioning is 407 percent for new construction and 120 percent for retrofits.

The BIDS™ team has identified three case studies that demonstrate HVAC energy savings due to mixed-mode conditioning or natural ventilation, with average savings of over 59 percent annually. Two case studies show health cost reductions, with an average savings of $60 per employee per year. Six case studies show individual productivity improvements due to mixed-mode or natural ventilation, with an average improvement of nearly 9 percent annually.

4.2 High Performance Equipment

The first trade-off in a value engineering excercise is typically to reduce the quality of the equipment and appliances that have been specified. Even short-term energy savings do not seem to be enough to drive decisionmakers towards quality. Either performance standards or links to productivity, health and other life cycle variables will be critical to promoting high performance equipment.

For example, the introduction of California and then national standards for equipment and appliance efficiency has had a major impact on national energy use, reducing overall energy consumption for heating, cooling and refrigeration by 25 percent, 40 percent and 75 percent respectively.[19] The direct relationship of appliance electricity demand and CO2 production illustrates the value of these energy savings in addressing climate change and reducing pollution from power plants. The impact of both R&D and standards has enabled refrigerator size and amenities to increase while overall energy use is reduced.[20] Four pending appliance standards (clothes washers, fluorescent light ballasts, water heaters and central air conditioners) are projected to save consumers $10 billion in unnecessary energy costs, improve functionality, and reduce cumulative emissions by as much as 80 Tg CO2 equivalent through 2010.[21] Given the natural replacement cycle of building appliances and equipment, 190 billion kWh of power demand can be eliminated by 2010 and another 130 billion kWh and .3Mbod can be eliminated by 2050 by just four building technologies—ballasts, lamps, windows, and refrigerator/freezers. There are few engineering obstacles and significant export growth potential in expanding appliance and equipment energy efficiency standards to cover the full range of existing and new equipment being introduced in residential and commercial buildings. Barring this commitment from the federal government or states, however, practitioners will need to use every life cycle value in their promotion of high performance technologies.

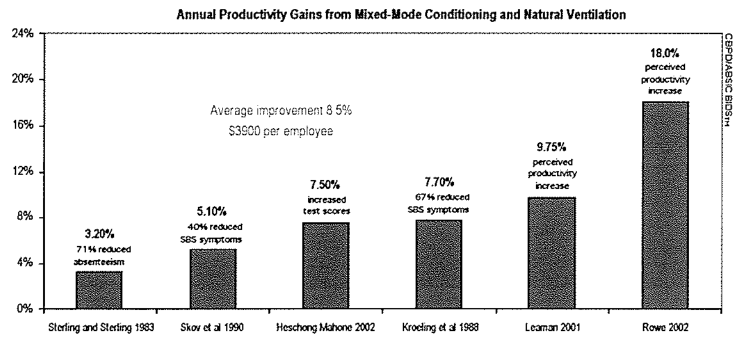


Figure 12 Productivity Benefits Associated with Natural Ventilation and Mixed-mode Conditioning (http://cbpd.arc.cmu.edu/ebids)

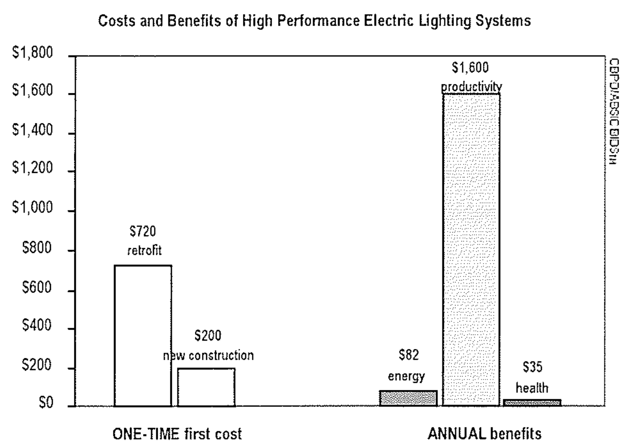


Figure 13. Costs and Benefits of High Performance Electric Lighting Systems. (http://cbpd.arc.cmu.edu/ebids)

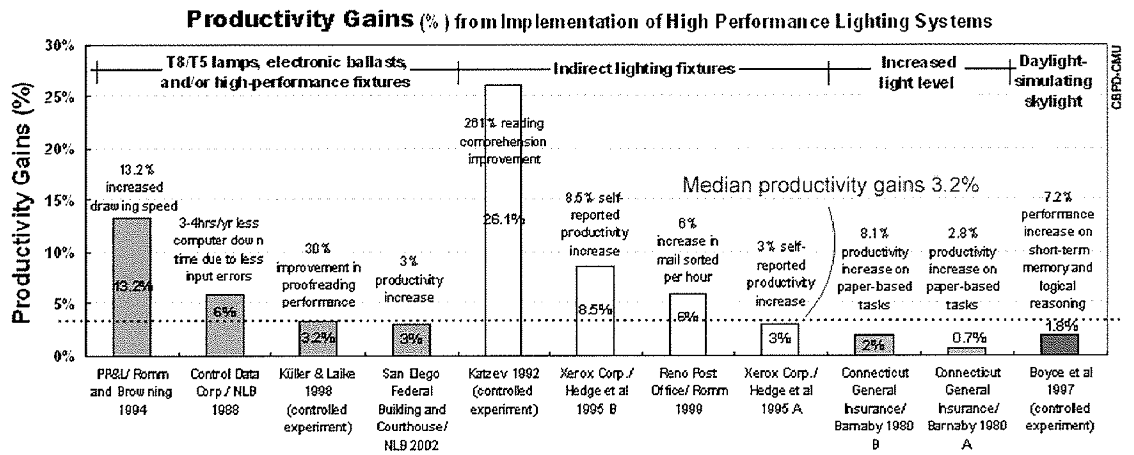


Figure 14. Productivity Benefits Associated with High Performance Lighting Systems (http://cbpd.arc.cmu.edu/ebids

High Performance Lighting Pays!

Replace outdated office lighting with quality electric lighting systems featuring high-performance lamps, ballasts, fixture and advanced controls for 27-87 percent lighting energy savings, 0.7-26 percent productivity gains, and 27 percent headache reduc-tion, with ROIs over 236 percent.

Twenty-five studies have helped to quantify the assertion that high performance lighting systems can pay for themselves in less than one year due to energy, productivity and health benefits. These studies demonstrate that daylighting yields annual energy cost savings of $82 per employee ($0.41 per square foot), annual productivity gains of $1,600 per employee, and annual health cost savings of $20 per employee, for total savings of up to $1,702 per employee annually. With a median first cost of $720 per employee for lighting retrofits ($3.60 per square foot, range of $0.63 to $7.45), and a median first cost increase of $200 per employee for high performance lighting systems in new construction ($1 per square foot, range $0.26 to $10.65), an investment in high performance electric lighting results in an ROI of 236 percent for retrofits and 851 percent for new construction.

Specifically, the BIDS™ has identified 15 case studies indicating a link between improved lighting design and annual lighting energy savings, with a median savings of 60 percent, or $79 per employee per year. Six case studies identify a link between improved lighting design and total annual energy savings, including lighting, cooling and associated HVAC energy consumption reductions, with a median savings of 18 percent, including an additional $3 to yield $82 per employee per year. The average lighting energy savings is 4.9 kWh per square foot annually, and the additional cooling energy savings averages 0.2 kWh per square foot per year. More financially signicant, however, nine case studies identify a link between improved lighting design and individual productivity gains, with a median improvement of 3.2 percent or $1,600 per employee per year. Across these studies, productivity is measured by improved working speed, reduced error rate, improved reading comprehension, improved short-term memory and logical reasoning, and by self-reported increases in productivity. Finally, a 1988 controlled experiment by Aars et al identifies a link between improved lighting design and 27 percent reduced incidence of headache, which accounts for 0.7 percent of overall employee health insurance cost or $35 per employee annually.[22]

4.3 Shading, Cool roofs and cool communities

Where once shading through massing, orientation, external and internal shading devices was integral with the aesthetics of place, the shading of buildings and communities today is a lost art. Again, first-least-cost decisionmaking will not support the dynamic and elegantly crafted solutions for shading that are invaluable to sustainable environments. Consequently, we must build the life-cycle proofs to support shading, landscaping and cool roof technologies, searching for energy, health, crime, maintenance and other benefits to promote investments in quality built environments.

Six percent of all United States electricity is used in cooling residential and commercial buildings,[23] at an annual cost of 40 billion, and peak power demands of 250 GW. A 5°F rise in neighborhood temper-atures—from excessive absorption of solar energy in our increasingly impervious built environment—increases cooling loads and raises the rate at which nitrogen oxides and VOC emissions from cars and smokestacks contribute to smog and ozone depletion. Indicative of many cities, Los Angeles now has over 10% impervious and highly absorptive surfaces in roads, parking lots and roofs. On a national level, the creation of "cool communities" with white roofs, pervious paving, and shade trees would yield a 10 percent reduction in annual cooling loads, and a 5 percent reduction in peak cooling loads.[24] Smog would drop by 6-8 percent and health related costs would be commensurately reduced. Moreover, local CO^2 would be sequestered by urban trees more effectively than an equivalent number of new 'forest' trees, and urban flooding would be reduced. Given the cycle time of roof replacements and tree growth rates, immediate federal and state policies and incentives are needed to realize the 2020 benefits of "cool communities" or architects and building owners will need to assemble convincing life-cycle data for cool roof technologies and cool community designs.

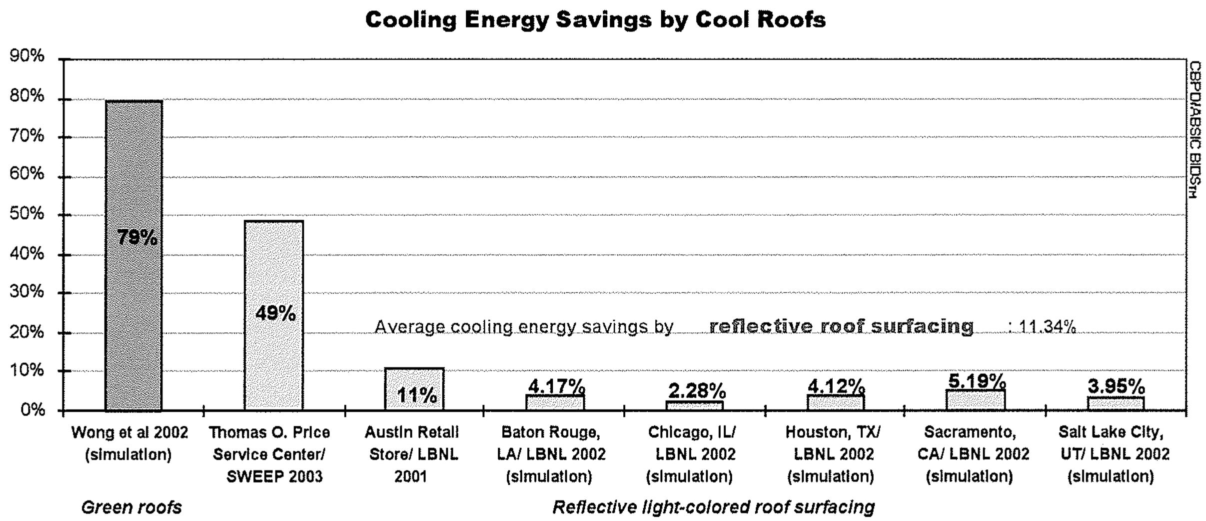


Figure 15. Cooling Energy Savings Associated with Cool Roofs (http://cbpd.arc.cmu.edu/ebids)

Cool Roofs Pay!

Replace conventional dark roofs with cool roofing for 2-79 percent cooling energy savings and 14-79 percent peak cooling demand reduction.

CMU's BIDS™ team has identified seven case studies indicating a link between reflective light-colored roofs and 2.3 percent to 49 percent reductions in annual cooling energy consumption, with an average savings of 11.3 percent or $0.02 per square foot. Reflective roofing has also been associated with an average peak cooling demand reduction of 14 percent. The average ROI for an investment in reflective roofing is 120 percent. Given the small price penalty for light colored roofs ($0.02/sq.ft. additional), the cooling energy savings can secure less than 1 to 5 year paybacks.

Although significantly more costly (at $6.5/sq.ft. average cost differential), 'extensive' (non-walk-able) green roof technologies are rapidly appearing in the United States From a series of energy simulations, Wong et al.[25] concludes that green roofs provide 48 percent average cooling energy savings (range 17– 79 percent), 8 percent average total energy savings (range 1– 15 percent), and an average 48 percent peak load reduction (range 17-79 percent). Based on this study, the optimum roof garden, composed of 300 mm thick soil and shrubs, can achieve a savings of 15 percent in annual energy consumption, 79 percent in space cooling load, and 79 percent in peak load. With an estimated total energy savings of $0.34 per square foot, the ROI for an investment in this optimum green roof is 5 percent.

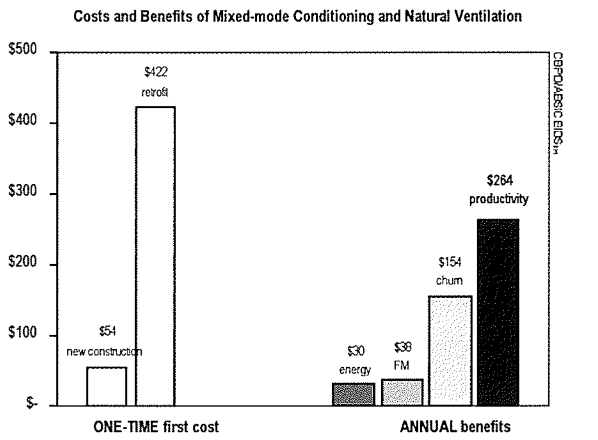


Figure 16. Cost and Benefits of Underfloor Air Systems (http://cbpd.arc.cmu.edu/ebids)

4.4 Innovative Systems Integration

There are a growing number of LEED® Silver, Gold and Platinum projects that have demonstrated measurable energy benefits as well as reduced absenteeism, quicker attraction rates, better health statistics, and more. The difficulty lies is determining which elements of the building contributed most significantly to those gains—access to the natural environemnt, high performance equipment, better materials and finish, or better coordination of the professional disciplines driven to create a more sustainable building. As we strive for innovation in buildings to ensure health and productivity, organizational and technological flexibility, and environmental sustainability, it will be critical to tease out the importance of quality in each building subsystem and system integration. To this end, one systems integration innovation, the use of underfloor air to ensure task air for each individual, has demonstrated life cycle benefits.

Task Air Pays!
Underfloor Air Systems

Implement under floor air systems to ensure 5-34 percent annual HVAC energy savings and 67-90 percent annual churn costs savings, for an ROI of at least 115 percent.

Twelve studies have shown that UFA systems can pay for themselves in less than one year due to energy, productivity, churn, and facility management benefits. The BIDS™ case studies demonstrate that UFA yields annual energy cost savings of $30 per employee ($0.14/ft2), produc-tivity gains of $254 per employee, churn cost savings of $154 per employee, and FM savings of $38 per employee ($0.19/ft2), for total savings of up to $486 per employee annually. With a one-time first cost premium of $54 per employee for new construction and $422 per employee to modify existing buildings, the average ROI for an investment in UFA is 900 percent for new buildings and 115 percent for retrofits.

The BIDS™ team has identified four case studies that indicate an average 15 percent reduction in annual HVAC energy consumption due to underfloor air systems. Five studies demonstrate an average 80 percent reduction in annual organizational churn cost due to UFA. Two studies report first cost savings of $0.43 to $2.00 per square foot for UFA systems, as compared to ceiling-based systems, while other case studies argue a first cost premium of $0.25 to $2.50/sq.ft. York[26] identifies annual FM staffing cost savings of $0.19 per square foot and Fitzner[27] shows an individual productivity improvement of 0.7 percent, both resulting from the introduction of underfloor HVAC, with the ability to customize the delivery of air in the individual workstation.

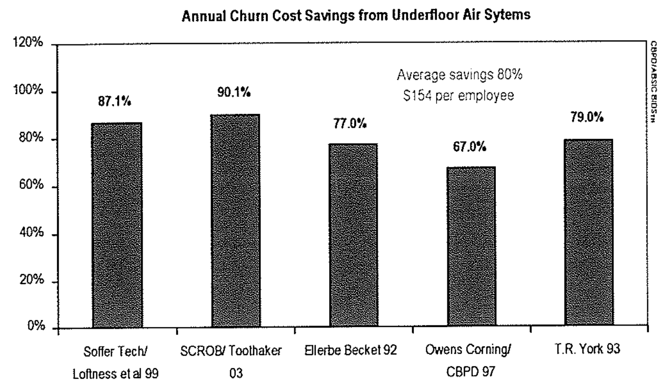


Figure 17. Churn Cost Savings Associated with Underfloor Air Systems (http://cbpd.arc.cmu.edu/ebids)

5. Conclusion

Sustainable design is a collective process whereby the built environment achieves new 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 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, achieved through life-cycle instead of least-cost investments, and through timeless delight and craftsmanship.[28]

Notes

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