GREENING THE BUILDING AND THE BOTTOM LINE

Increasing Productivity Through Energy-Efficient Design

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Executive Summary

Energy-efficient building and office design offers the possibility of significantly increased worker productivity. By improving lighting, heating, and cooling, workers can be made more comfortable and productive. An increase of 1 percent in productivity can provide savings to a company that exceed its entire energy bill. Efficient design practices are cost-effective just from their energy savings; the resulting productivity gains make them indispensable.

This paper documents eight cases in which efficient lighting, heating, and cooling have measurably increased worker productivity, decreased absenteeism, and/or improved the quality of work performed. They also show that efficient lighting can measurably increase work quality by reducing errors and manufacturing defects.

The case studies presented here include retrofits of existing buildings and the design of new facilities, and cover a variety of commercial and industrial settings. They include:

• The main post office of Reno, Nevada, a lighting retrofit with a six-year payback that led to a 6-percent gain in productivity—worth more than the cost of the retrofit.

• Boeing's "Green Lights" effort, which reduced its lighting electricity use by up to 90 percent, with a two-year payback (a 53-percent return on investment) and reduced defects.

• Hyde Tools' implementation of a lighting retrofit with a one-year payback and an increase in product quality estimated to be worth $25,000 annually.

• Pennsylvania Power & Light's upgrade of the lighting system in a drafting facility that produced energy savings of 69 percent and a 13-percent increase in productivity, with a 25-percent decrease in absenteeism.

• Lockheed's engineering development and design facility, which saved nearly $500,000 a year on energy bills and gained 15 percent in productivity with a 15-percent drop in absenteeism.

• West Bend Mutual Insurance's new building, which yielded a 40-percent reduction in energy consumption per square foot and a 16-percent increase in claim-processing productivity.

• Wal-Mart's new prototype Eco-Mart, where enhanced daylighting through the use of skylights in one half of the store led to "significantly higher" sales than in the other half.

• ING Bank's new headquarters, which used one-tenth the energy per square foot of its predecessor, created a positive new image for the bank, and lowered absenteeism by 15 percent.

Each case study identifies the design changes that were most responsible for increased productivity. While such gains may not necessarily be achievable by all companies, the cases profiled in this paper are by no means out of the ordinary. These companies realized significant productivity and energy savings because their former offices and plants were inefficient—but no more so than those of most American companies.

As these eight case studies illustrate, energy-efficient design may be one of the least expensive ways for a business to improve the productivity of its workers and the quality of its product.

Introduction

This paper describes case studies of companies that undertook to increase the energy efficiency of buildings, and thereby inadvertently increased worker productivity.

Energy-efficiency retrofits for existing buildings, and new buildings designed for energy-efficient performance, have very attractive economic returns. For example, a three-year payback, typical in lighting retrofits, is equal to an internal rate of return in excess of 30 percent. This return is well above the "hurdle rate" of most financial managers. The same retrofit may also cut energy use by 50¢ or more per square foot, which has significant positive effects on the net operating income of a building.

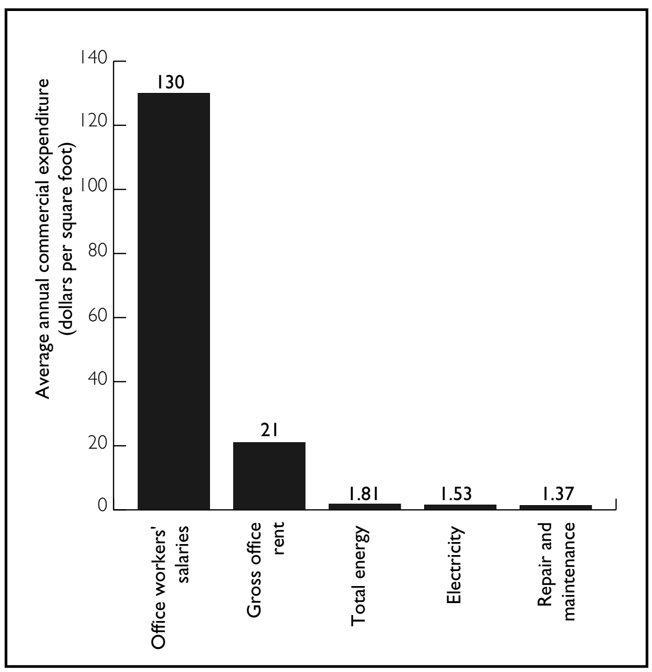
However, these gains are tiny compared to the cost of employees, which is greater than the total energy and operating costs of a building. Based on a 1990 national survey of large office buildings[1], as summarized in the graph below, electricity typically costs $1.53 per square foot and accounts for 85 percent of the total energy bill, while repairs and maintenance typically add another $1.37 per square foot; both contribute to the gross office-space rent of $21 per square foot. In comparison, office workers cost $130 per square foot[2]—72 times as much as the energy costs. Thus an increase of 1 percent in productivity can nearly offset a company's entire annual energy cost.

Productivity is measured here in terms of production rate, quality of production, and changes in absenteeism. This can be improved by fewer distractions from eye strain or poor thermal comfort, and similar factors.

Research done at Western Electric in the 1920s and '30s suggests that contrived experiments to monitor the effect of a workplace change on productivity can be complicated by the special conditions of the experiment, particularly the interaction between the worker and the researcher. Indeed, some have come to see the "Hawthorne effect" as implying that changes in the physical environment have an effect on worker performance only because those changes signal to the worker the interest and concern of management.[3] Subsequent analyses, however, have called into question the experimental methods and results from this work. A major 1984 study of the effect of office design on productivity found direct correlation between specific changes in the physical environment and worker productivity.

It is important to note that increases in worker productivity were not the reason for the measures described in these case studies. The companies based their decisions solely on projected energy and maintenance savings. In all the examples, productivity had always been monitored by the companies. Additionally, none of the cases involved a change in management style. The gains in productivity observed by the companies were for the most part unanticipated. Some of the companies were aware that the measures implemented would improve the quality of spaces.

The measures described were not undertaken for energy *conservation*, but rather to increase energy *efficiency*. Both activities lower energy consumption. However, conservation implies a decrease in service; energy efficiency must meet or exceed the quality of service that it replaces.



Data from Building Owners and Managers Association; Electric Power Research Institute; Statistical Abstract of the United States 1991.

Retrofit case studies

Reno Post Office

In 1986, the mail sorters at the Main Post Office in Reno, Nevada[4] became the most productive of all the sorters in the entire western region of the United States, which stretches from Colorado to Hawaii. At the same time, the operators of one of their two mechanized sorting machines achieved the lowest error rate for sorting in the western region. What happened?

It began a few years earlier when the Reno Post Office was selected by the federal government to receive a renovation that would make it a "minimum energy user." An architectural firm, Leo A. Daly, was hired to do everything necessary to reduce energy use.

The post office was a modern warehouse with high ceilings and coal-black floors. It was quite noisy in the areas where the two sorting machines were run. The sorter is grueling to use. Once a second, it drops a letter in front of the operator, who must punch in the correct zip code before the next letter appears. If the operator keys in a zip code that doesn't exist, or no zip code at all, the letter will immediately be sent back through the machine for repunching. If the wrong zip code is keyed in, the letter will be sent to the wrong bin and it will take even longer to track down the mistake. The job is so stressful that an operator can work a maximum of only 30 minutes on the machine at one time.

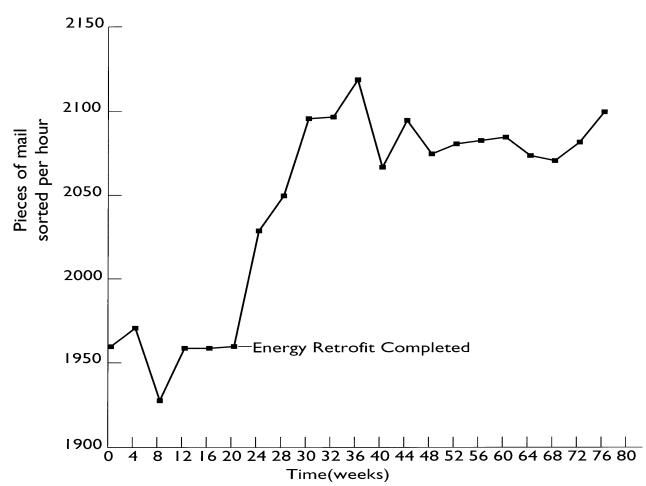
The chief architect, Lee Windheim, proposed a lowered ceiling and improved lighting. The new ceiling would make the room easier to heat and cool, while also creating better acoustics. The ceiling would be sloped to enhance the indirect lighting, and to replace harsh direct downlighting. More efficient, longer-lasting lamps that gave off a more pleasant light quality were installed.

Before starting the complete renovation, estimated to cost about $300,000, Windheim did a small test section of the lighting and new ceiling over one of the two sorting machines. The graph at right shows the number of pieces of mail sorted per hour in the 24 weeks before the change, and for more than a year after the change.

In the next 20 weeks, productivity increased more than 8 percent. The workers in the area with the old ceiling and lighting showed no change in productivity. A year later, productivity had stabilized at an increase of about 6 percent. Under the new lighting design, the rate of sorting errors by machine operators dropped to 0.1 percent—only one mistake in every 1,000 letters—the lowest error rate in the entire western region. Working in a quieter and more comfortably lit work area, postal employees did their jobs better and faster. The manager of mail processing, Robert McLean, says the data were "solid enough to get $300,000 to do the whole building."

The energy savings projected for the whole building came to about $22,400 a year. There would be an additional savings of $30,000 a year because the new ceiling would require less frequent repainting. Combined, the energy and maintenance savings came to about $50,000 a year: a six-year payback. The productivity gains, however, were worth $400,000 to $500,000 a year. In other words, the productivity gains alone would pay for the entire renovation in less than a year. The annual savings in energy use and maintenance were a free bonus.

At the Reno Post Office, no one conducted any special experiment intended to raise productivity, and there was no unusual interaction between workers and supervisors. Productivity had always been measured. McLean, now postmaster for Carson City, denies any personal responsibility for the improvement. "We had the same people, the same supervisor, and I don't believe I was doing any motivational work," he says. Yet he notes that the data on the productivity and quality increase were "irrefutable." The changes to the building were designed solely to reduce energy use. The increases in productivity were unexpected.



Productivity gain after retrofit

Boeing

Boeing[5] participates in the Environmental Protection Agency's voluntary "Green Lights" program to promote energy-efficient lighting. To date, the aircraft manufacturer has retrofitted more than 1 million of the 8 million square feet of assembly space in its hangar-sized assembly plants near Seattle.

Using various efficiency measures, Boeing has reduced lighting electricity use by up to 90 percent in some of its plants, and the company calculates its overall return on investment in the new lighting to be 53 percent—the energy savings pay for the lights in just two years. Lawrence Friedman, then Boeing's conservation manager, notes that if every company adopted the lighting Boeing has installed, "it would reduce air pollution as much as if one-third of the cars on the road today never left the garage."

However, Boeing has discovered even more interesting results from its lighting retrofit.

With the new efficient lighting, employees have more control, the interior looks nicer, and glare has been reduced. Friedman says that after the new lighting was put in, "The things that people tell us are almost mind-boggling." One woman, who puts rivets in 30-foot wing supports, had been relying on touch with one part because she was unable to see inside. Now, for the first time in 12 years, she could actually see inside the part. Another riveter reported that it's much safer. With the old lighting, a rivet head would occasionally break off, fly through the air, hit one of the old fluorescent light tubes, and possibly break the lamp. The new high-efficiency metal-halide lamps have hard plastic covers that don't break when a flying rivet head hits them. Steve Cassens, a lighting engineer for Boeing, says that the first thing machinists with new lighting tell him is that they can read the calipers on their lathes and measurement tools much more easily.

One shop that produced the interior sidewall panel for jets was moved from an area with old fluorescents into an area with high-efficiency metal-halide lamps. One of the tasks performed by machinists in the shop is to attach a panel to a stiffening member using numerous fasteners, which leave very small indentations in the panel. The old lighting had poor contrast and made it difficult to tell if a fastener had been properly attached. With the new lighting, the indentations left by properly attached fasteners are far easier to detect; it improves workers' ability to detect imperfections in the shop by 20 percent.[6]

Friedman says that most of the errors in the aircraft interiors that used to slip through "weren't being picked up until installation in the airplane, where it is much more expensive to fix." Even worse, some imperfections were found during customer walk-throughs, which is embarrassing, and costly. Although it is difficult to calculate the savings from catching errors early, a senior manager estimates that they exceed the energy savings for that building.

HYDE TOOLS

Hyde Tools[7], a Massachusetts-based manufacturer of cutting blades, has 300 employees. An environmentally proactive company, Hyde decided in the early 1990s that it could save energy and improve its bottom line by upgrading its lighting from old fluorescents to new high-pressure sodium-vapor and metal-halide fixtures.

The cost of the retrofit was $98,000 (including labor), with $48,000 covered by the local utility. Doug DeVries, then the company's purchasing manager, estimated that annual energy savings would also come to $48,000—yielding a payback of about one year—but he still insisted in trying the upgrade in only one area to start. He gave workers the option of restoring the original lighting after a six-month trial period, on the principle that no amount of energy saved would be worth making his operators dissatisfied.

"For the first three weeks, a lot of people complained because the new lights cast an orange hue," says DeVries. "But when we experimented by turning the old fluorescent lights back on after six months, there was a near riot of disapproval." Why? Because the new lights had made it possible to see tiny specks of dirt on the equipment that holds the blades while they're being worked on. That dirt creates tiny indentations on a blade, called "mud holes." The mud holes make the blade defective or difficult to plate, which can cause a customer to reject it.

With the new lighting, DeVries says, "the quality of work improved significantly because we could see things we couldn't see before." DeVries estimates that the improved quality was worth another $25,000 a year to the company. Those bottom-line savings are critical to a small company. DeVries notes that every dollar saved on the shop floor is worth $10 in direct sales. In other words, the improved quality from the efficient lighting was the equivalent of a $250,000 increase in sales.

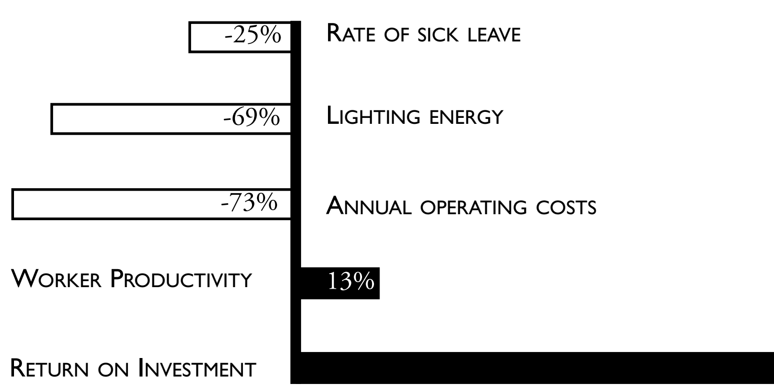
PENNSYLVANIA POWER & LIGHT

In the early 1980s, Pennsylvania Power & Light[8] became increasingly concerned about the lighting system in a 12,775-square-foot room that housed its drafting engineers. According to Russell Allen, superintendent of the office complex, "The single most serious problem was veiling reflections, a form of indirect glare that occurs when light from a source bounces off the task surface and into a worker's eyes."

Veiling reflections "wash out the contrast between the foreground and background of a task surface, making it more difficult to see." This increases the time required to perform a task and the number of errors likely to be made. Allen adds: "Low-quality seeing conditions were also causing morale problems among employees. In addition to the veiling reflections, workers were experiencing eye strain and headaches that resulted in sick leave."

After considering many suggestions, the utility decided to upgrade the lighting in a 2,275-square-foot area with high-efficiency lamps and ballasts. Rather than just swapping out lamps in the old fixtures that ran perpendicular to the workstations, the new fixtures were reconfigured and installed parallel to reduce veiling reflections. To improve lighting quality still further, the fixtures were fitted with eight-cell parabolic louvers—metal grids that help reduce glare. Allen notes, "Generally speaking, it can be said that we converted from general lighting to task lighting. As a result, more of the light is directed specifically to work areas and less is applied to circulation areas,

Results of Pennsylvania Power & Light's retrofit



creating more variance in lighting levels which upgrades the appearance of the space."

With veiling reflections reduced, less light was needed to provide better visibility. Allen believes this general principle: "As lighting quality is improved, lighting quantity can often be reduced, resulting in more task visibility and less energy consumption."

Finally, local controls were installed to permit more selective use of lighting during clean-up and occasional overtime hours. Previously, all the lighting was controlled by one switch and every fixture had to be on during clean-up. With multiple circuits, maintenance crews can now turn the lights on and off as they move from one area to the next.

Allen performed a detailed cost analysis, comparing the initial capital and labor costs of purchasing and installing the new lighting with the total annual operating costs, including energy consumption, replacement lamps and ballasts, fixture cleaning and lamp replacement labor.

The total net cost of the changes amounted to $8,362. Lighting energy use dropped by 69 percent, and total annual operating costs fell 73 percent, from $2,800 to $765. This $2,035 annual savings alone would have paid for the improvement in 4.1 years, a 24-percent return on investment. (In addition, the new lighting lowered heat loads, and therefore space cooling costs.)

Under the improved lighting, productivity also jumped by 13.2 percent. In the prior year, it had taken a drafter 6.93 hours on average to complete one drawing, a productivity rate of 0.144 drawings per hour. After the upgrade, "the time required to produce a drawing dropped to an average of 6.15 hours, boosting the productivity rate to 0.163 drawings per hour." This gain was worth $42,240 a year, reducing the simple payback from 4.1 years to 69 *days*. The productivity gain turned a 24-percent return on investment into a 540-percent return!

"Not only is this an amazing benefit," comments Allen, but "it is only one of several." Before the upgrade, drafters in the area had used about 72 hours of sick leave a year. After the upgrade, the rate dropped 25 percent to 54 hours a year. The better appearance of the space, reduced eye fatigue and headaches, and the overall improvement in working conditions all helped boost morale.

Finally, supervisors report that the new lighting has reduced the number of errors. Better lighting means higher-quality work. Allen says of the reduced error rate: "We are unable to gather any meaningful data on the value of these savings because any given error could result in a needless expense of thousands of dollars. Personally, I would have no qualms in indicating that the value of reduced errors is at least $50,000 a year." If this estimate were included in the calculation, the return on investment would exceed 1,000 percent.

540%

New Building Case Studies

Lockheed Building 157

One of the most successful examples of daylighting in a large commercial office building is Lockheed's Building 157 in Sunnyvale, California[9]. In 1979, Lockheed Missiles and Space Company commissioned the architectural firm, Leo A. Daly, to design a new 600,000-square-foot office building for 2,700 engineers and support people.

The architects posed a question to Lockheed: "If we could design a building for you that would use half as much energy as the one you're planning to build, would you be interested?" Lockheed said yes, and Daly's architects responded with a design for energy-conscious daylighting that was completed in 1983.

Daly used 15-foot-high window walls with sloped ceilings to bring daylight deep into the building. "High windows were the secret to deep daylighting success," says the project architect, Lee Windheim. "The sloped ceiling directs additional daylight to the center of each floor and decreases the perception of crowded space in a very densely populated building."

Daylighting is also enhanced by a central atrium, or "litetrium," as the architects call it. The litetrium runs top to bottom and has a glazed roof. Workers consider it the building's most attractive feature. Other light-enhancing features include exterior "light shelves" on the south facade. These operate as sunshades or as reflectors for bouncing light onto the interior ceiling from the high summer sun; in the winter, when the sun's angle is lower, they diffuse reflected light and reduce glare.

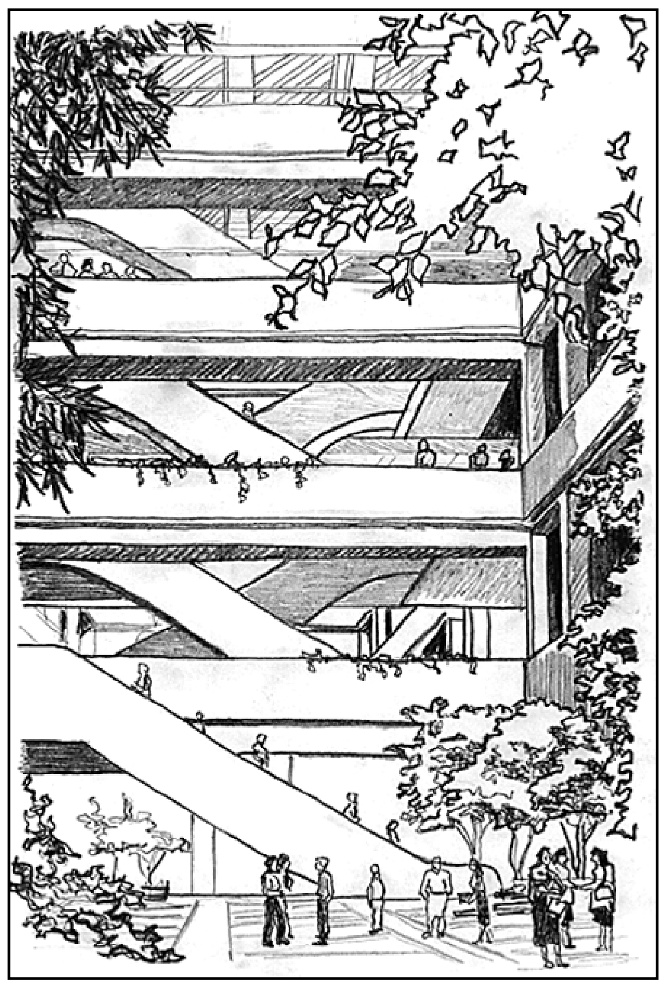
The overall design separates ambient and task lighting, with daylight supplying most of the ambient lighting and task lighting fixtures supplementing each workstation. Continuously dimmable fluorescents with photocell sensors maintain a constant level of light automatically to save even more energy.

The open office layout and a large cafeteria were designed to foster interaction among the engineers. At the same time, workstations were tailored for employee needs. They included acoustic panels and chambers to block out ambient noise. When a worker moves forward into a chamber, the annoying sound of telephones becomes practically inaudible. Ambient noise was further controlled by sound-absorbing ceilings and speakers that introduced background white noise on each floor.

Employees love the building. More than a year after occupancy, a survey of workers at the building included the following representative responses.

"My work space," says engineer Ben Kimura, "is 15 feet from the litetrium and the lighting is great. The office decor, arrangement, and temperature are ideal. There are many people working on this floor, but the feeling is not one of crowding, but of spaciousness. Interface with other departments is greatly facilitated because we're finally all in one building. By nature I'm very cynical, but the conditions in this building are far superior to any I've experienced in 30 years in the aerospace industry."

"I love my work space," says financial controller Joanne Navarini. "I think the building itself is very pret-



Lockheed Building 157

ty; my own workstation is very functional. I am five workstations from the window and the light is fine. I use my task light and could order an additional desk lamp if I felt the need to. I like the daylight." Daylighting has saved Lockheed about 75 percent on its lighting bill. Since daylight generates less heat than office lights, the peak air-conditioning load has also been reduced. Overall, the building runs with about half of the energy costs of a typical building constructed at that time.

Daly's energy-efficient improvements added roughly $2 million to the $50 million cost of the building. The energy savings alone were worth nearly $500,000 a year. The improvements paid for themselves in a little over four years.

Perhaps more important, Russell Robinson, manger of Facility Interior Development, reported that productivity is up because absenteeism has declined. Lockheed itself has never published the figures concerning the improvements in absenteeism and productivity. But according to Don Aitken, then chairman of the Department of Environmental Studies at San Jose State, "Lockheed moved a known population of workers into the building and absenteeism dropped 15 percent." Aitken led numerous tours of Building 157 after it opened and was told by Lockheed officials that the reduced absenteeism paid 100 percent of the extra cost of the building in the first year.

The architect, Lee Windheim, also reports that Lockheed officials told him that productivity rose 15 percent on the first major contract done in the building compared to previous contracts done by those Lockheed engineers. Aitken reported something even more astonishing: Top Lockheed officials told him that they believe they won a very competitive $1.5 billion defense contract on the basis of their improved productivity—and that the profits from that contract paid for the entire building.

West Bend Mutual Insurance

West Bend Mutual Insurance Company's new 150,000-square-foot headquarters in West Bend, Wisconsin[10] is the subject of one of the most carefully documented increases in productivity due to green design. The West Bend Mutual building won the 1992 Intellex Building for Excellence Award, cosponsored by *Consulting-Specifying Engineer* magazine and the Intelligent Buildings Institute.

The building has a number of energy-saving design features, including an energy-efficient lighting system (including task lighting and occupancy sensors), better windows, shell insulation, and a more efficient heating, ventilation, and air-conditioning (HVAC) system. It uses a thermal-storage system that makes ice overnight to help cool the building during the day. These measures allowed West Bend Mutual to get utility rebates that kept the project within its $90-per-square-foot budget.

Enclosed offices all have individual temperature control. But the most hi-tech feature of the building is its "environmentally responsive workstations" (ERWs). Workers in open-office areas are given direct, individual control over temperature and airflow. Radiant heaters and vents are built directly into their furniture and controlled by a panel on their desks. The control panel also provides direct control of task lighting and white-noise levels. A motion sensor in each ERW turns the workstation off when the worker leaves the space and turns it back on when he or she returns.

Giving workers direct control over their environment allows individuals working near each other to have very different temperatures in their spaces. The entire HVAC system no longer needs to be driven by a manager, or by a few vocal employees, who want it hotter or colder than everyone else. The motion sensors save even more energy. It's worth noting that before the move into the new building, West Bend Mutual employees were given the chance to try out and comment on a full-scale demo of the ERWs. The outspoken workers were allowed to test ERWs at their own desks.

The annual electricity costs in the old building were $2.16 per square foot. The annual electricity costs in the new building are $1.32 per square foot. This 40-percent reduction is all the more impressive, given that the old building got its heat from gas-fired boilers while the new building is completely electric.

The Center for Architectural Research and the Center for Services Research and Education at the Rensselaer Polytechnic Institute (RPI) in Troy, New York conducted a detailed study of productivity in the old building in the 26 weeks before the move and in the new building for 24 weeks after the move. The RPI study made use of a productivity assessment system used by West Bend Mutual for many years, which basically tracked the number of insurance files processed by each employee per week. Researchers also conducted a detailed survey of workers' perceived levels of comfort, air quality, noise control, privacy, and lighting, both before and after the move.[11] The conclusion of the RPI study: "The combined effect of the new building and ERWs produced a statistically significant median increase in productivity of approximately 16 percent over productivity in the old building."

In an attempt to determine just how much of the productivity gain was due to the ERWs, the units were turned off randomly during a two-week period for a fraction of the workers. The researchers concluded, "Our best estimate is that ERWs were responsible for an increase in productivity of about 2.8 percent relative to productivity levels in the old building." The company's annual payroll is about $13 million, so even a 2.8-percent gain in productivity is worth about $364,000. The 2.8 percent figure almost certainly underestimates the actually benefit of the ERWs, according to West Bend Mutual senior vice president Ronald W. Lauret. Lauret observes that many workers demanded that their units be turned back on immediately. Some even threatened to go home (they were eliminated from the study). He estimates that if those employees were factored back in, the productivity gain from the ERWs alone would have been 4 percent to 6 percent. The remainder of the productivity gain may be due to the building's other efficiency measures.

Attention to the West Bend Mutual study has focused almost exclusively on the ERWs. The real lesson from West Bend Mutual should be that while the ERWs are interesting and probably worth further experimentation, the most significant gains in productivity may have come from the building design and systems.

WAL-MART

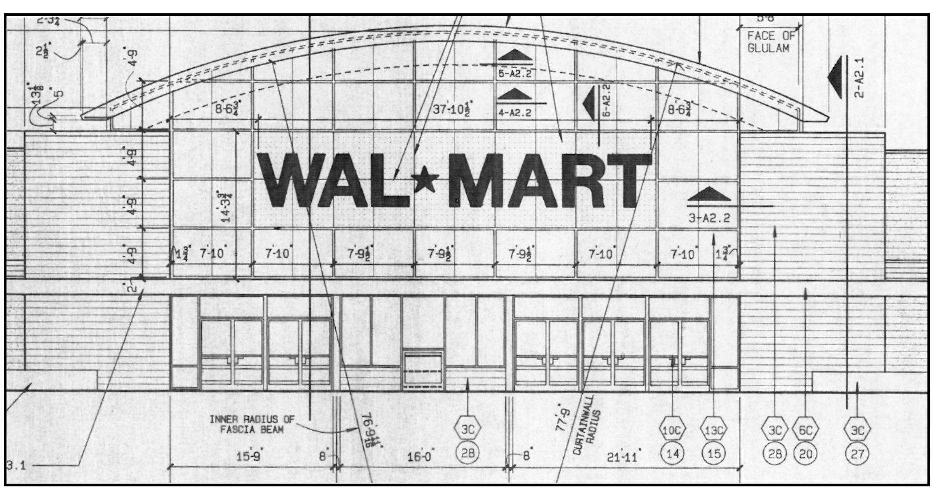
In June 1993, a new prototype Wal-Mart store opened in Lawrence, Kansas.[12] Called the "Eco-Mart," the building is an experimental foray into sustainable design by the nation's largest retailer. The project was led by Wal-Mart's Environment Committee and BSW Architects of Tulsa, Oklahoma. The design consulting team involved a number of firms, including Center for Resource Management, William McDonough Architects, and Rocky Mountain Institute. The team focused on experimenting with a series of environmentally responsive design strategies and technologies.

Elements of the experiment included the use of native species for landscaping; a constructed wetlands for site runoff and as a source for irrigation; a building shell design for adaptive reuse as a multifamily housing complex; a structural roof system constructed from sustainably harvested timber; an environmental education center; and a recycling center. A major goal of the project was to design for energy efficiency. The building has a glass arch at the entrance for daylighting, an efficient lighting system, an HVAC system that utilizes ice-storage, and special light-monitoring skylights developed specifically for the project.

Construction costs for the Eco-Mart were about 20 percent higher than the average for other Wal-Mart stores. (Wal-Mart's normal costs are extremely low, and a building typically pays for its own construction cost in a three to five years.) Several factors accounted for the additional cost of this building: using sustainably harvested timber added 10 percent to the roof cost; the integration of systems was not optimized, resulting in a more expensive cooling system; and the building included elements not found in other stores (a recycling center, a McDonald's, and the light-monitoring skylights). As a cost-cutting measure, Wal-Mart decided to install skylights on only half of the roof, leaving the other half without daylighting.

Even with such focused effort on the design process, the building had some problems. The energy performance of the building could have been better. The controls on the lighting systems were not compatible with the ballasts. The ice-storage system leaked water, and due to the expanded hours of store operation, was not able to fully refreeze.

However, something else has gotten the corporation's attention. Each of Wal-Mart's cash registers is connected in real time back to headquarters in Bentonville, Arkansas, as part of the retailer's "just-in-time" stocking and distribution system. According to Tom Seay, Wal-Mart's vice president for real estate, register activity revealed that "sales pressure (sales per square foot) was significantly higher for those departments located in the daylit half of the store." Sales were also higher than for the same departments in other stores. Additionally, employees in the half without the skylights are arguing that their departments should be moved to the daylit side. Wal-Mart is now considering implementing many of the Eco-Mart measures in both new construction and existing stores.



Wal-Mart blueprints

ING BANK

In 1978, International Netherlands Group (ING) Bank, then known as Nederlandsche Middenstandsbank, needed a new image, and a new headquarters in Amsterdam[13]. According to Dr. Tie Liebe, head of the bank's development subsidiary, ING wanted a building that was "organic, which integrated art, natural materials, sunlight, plants, energy conservation, low noise, and water."

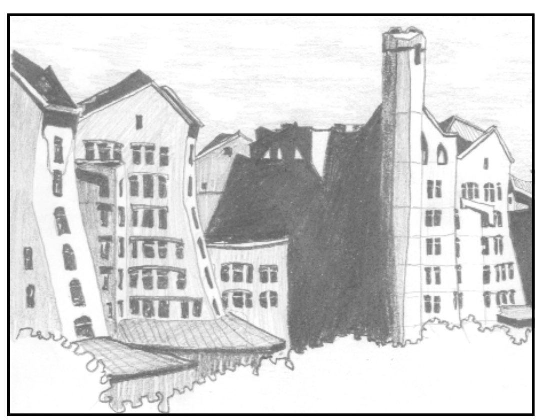
An integrated design team was instructed to work across disciplines—architects, construction engineers, landscape architects, energy experts, artists, and bank employees worked for three years on the design. The architect Anton Alberts describes the building, completed in 1987, as "anthroposophical," based on Rudolph Steiner's design philosophy. Rather than a monolithic tower, the 538,000-square-foot building is broken up into ten slanting towers. The irregular S-curve ground plan has gardens and courtyards interspersed over the top of parking and service areas. Restaurants and meeting rooms for the 2,400 employees line an internal street connecting the towers.

Like most northern European offices, the floor plates are narrow. All desks are located within 23 feet of a window for daylighting. Interior louvers in the top third of windows bounce daylight onto office ceilings. Atriums in the towers provide a significant portion of the lighting. Additional needs are met by task lighting, custom decorative wall sconces, and limited overhead fixtures. The building has double glazing, as it predates high-efficiency "superwindows." Insulation separates the brick skin from the precast-concrete structure, which is used to store heat from simple passive solar measures and internal gains. Additional heat is supplied through hydronic radiators connected to a 26,420-gallon hot-water storage system, heated by a cogeneration facility, and heat recovery from elevator motors and computer rooms. Air-to-air heat exchangers transfer the heat from exhaust air to intake air. The bank has no conventional compression chillers; it relies on the building's thermal storage, mechanical ventilation, natural ventilation through operable windows, and a back-up absorption cooling system powered by the cogeneration system's waste heat.

The integration of building design, daylighting, and energy systems has yielded impressive results. ING's former headquarters consumed 422,801 BTU per square foot per year of primary energy; the new building consumes 35,246 BTU per square foot. In comparison, an adjacent bank, constructed at approximately the same time and cost, consumes five times the energy per square foot.[14] Construction costs of $162 square foot (in 1991 dollars) included land, structure, landscaping, art, furniture, and equipment. Costs attributed to the energy systems were approximately $700,000, while annual energy savings are estimated at $2.6 million—in other words, using early-1980s technology, the energy measures paid for themselves in just three months.[15] According to Dr. Liebe, "construction costs were comparable to or cheaper than other office buildings in Holland," and ING's energy costs are among the lowest in the European office sector.

Sophisticated integration is evident from the artwork, plants, and "flow-form" sculptures. Expansion joints are treated as relief sculpture. Colored metal reflectors high in the atrium towers bathe lower spaces in colored light. Interiors feature a simple palette, textured paint over the precast concrete, wood trim, with wood slat and some drop ceilings. Cisterns capture rainwater for fountains and landscaping. Flow-form sculptures are used extensively, even in handrails, to create a pulsing, gurgling stream of water that adds visual appeal, moisture to the air, and a pleasing level of white noise in the corridors.

Absenteeism among ING employees has dropped, and remains 15 percent lower than in the bank's old building, Dr. Liebe attributes this to the better work environment. The building has done wonders for ING's image, he adds, noting that "ING is now seen as a progressive, creative bank, and the bank's business has grown dramatically."



ING Bank

Conclusion

The results of these case studies are compelling, for two reasons. First, the measurements of productivity in most of the cases came from records that were already kept, not from a new study. Second, the gains in productivity were sustained and not just a temporary effect.

Will just any energy retrofit produce gains in productivity? No, only those designs and actions that improve visual acuity and thermal comfort seem to result in these gains. This speaks directly to the need for good design, a total-quality approach that seeks to improve energy efficiency and improve the quality of workplaces by focusing on the end user—the employee. This is a point that seems to have been forgotten by many designers and building owners.

Clearly, there is a need for further research; however, the results of these few case studies indicate that the economic benefits of energy-efficient design may be significantly greater than just the energy cost savings. That energy efficiency provides numerous benefits has long been known. That it can lead to productivity gains far exceeding the energy savings gives it a new imperative.

Retrofits

Reno Post Office

Cost:	$300,000
Measures:	Lighting retrofit, new ceiling
Energy Savings/yr:	$22,400
Productivity:	6% increase in processing rate One year payback

Boeing

Cost:	N/A
Measures:	Lighting retrofit
Energy Savings/yr:	90% lighting electricity
Productivity:	20% improvement in defect rate

Hyde Tools

Cost:	$98,000
Measures:	Lighting retrofit
Energy Savings/yr:	$48,000
Productivity:	Improved product quality worth $25,000/yr.

Pennsylvania Power & Light

Cost:	$8,362
Measures:	Lighting retrofit
Energy Savings/yr:	$2,035
Productivity:	Increased drafting rate by 13.2% Absenteeism down 25%

New Buildings

Lockheed Building 157

Cost:	$2 million
Measures:	Daylighting, energy efficiency
Energy Savings/yr:	$500,000
Productivity:	15% rise in production Absenteeism down 15%

West Bend Mutual Insurance

Cost:	N/A
Measures:	Lighting, HVAC, individual controls
Energy Savings/yr:	40% electricity
Productivity:	16% increase in claims processed

Wal-Mart

Cost:	N/A
Measures:	Daylighting, HVAC
Energy Savings/yr:	N/A
Productivity:	Increased sales in the daylit portion of the store

ING Bank

Cost:	$700,000
Measures:	Daylighting, HVAC, overall building
Energy Savings/yr:	$2.6 million
Productivity:	Absenteeism down 15% New image for bank

NOTES

[1] Building Owners and Managers Association, *Experience Exchange Report 1991*, p. 95, showing 1990 national means for downtown private-sector office buildings of 100,000–300,000 square feet. Areas are net rentable space; income ($21) is for the office area only, versus $16.68 for the entire building including retail space, parking, etc. The energy costs, other costs, and income are probably somewhat higher for new offices than for the stock average described here, which is based on a sample of hundreds of buildings totaling more than 70 million square feet. The authors are grateful to BOMA for kindly making these proprietary data available.

[2] *Statistical Abstract of the United States 1991*, Table 678, p. 415, gives 1989 average office salaries whose weighted average was $27,939 per year. We nominally adjust this by 4.12 percent for 1989–90 monetary inflation (implicit GNP real price deflator) and add an estimated 20 percent for taxes and benefits, then divide by the BOMA 1990 national average of 268 square feet per office worker in 100,000–300,000-square-foot office buildings.

[3] For a survey of some of the literature on the flaws in the Hawthorne effect research—and a major study that came to a different conclusion—see Michael Brill et. al., *Using Office Design to Increase Productivity, Volume I* (Buffalo; Workplace Design and Productivity, Inc., 1984), pp. 224-25. See also William J. Dickson and F. J. Roethlisberger, *Counseling an Organization: A Sequel to the Hawthorne Researches* (Boston: Harvard University Press, 1986). This book explains that the traditional view of the Hawthorne Effect—that workplace environment affects productivity only because it signals management's interest in the worker—is very different from what the Hawthorne researchers themselves concluded from their work. They concluded that productivity can be enhanced by a more cooperative relationship between management and labor, a greater identification by workers with the goals of management, and more effort by management to treat workers with respect and to be responsive to their needs and abilities.

[4] The Reno Post Office case was developed from personal communications with Lee Windheim of Leo A. Daly and Robert McLean of the U.S. Postal Service.

[5] The discussion of Boeing is based on personal conversations with Larry Friedman and Steve Cassens, articles in *Boeing News* (May 10, 1991 and January 15, 1993), 1992 EPA data on the Green Lights program, and a site visit. DOE's Pacific Northwest Laboratory is now undertaking a detailed study of energy efficiency and productivity gains at Boeing.

[6] From Boeing's weekly newsletter, *Boeing News*, January 15, 1993, p. 5.

[7] The Hyde Tools study is based on an article in *TPM Newsletter*, January 1993, p. 7, and personal communication with Doug DeVries.

[8] This case study is based on Russell Allen, "Pennsylvania Power and Light: A Lighting Case Study," *Buildings*, March 1982, pp. 49–56; and "Office Lighting Retrofit Will Pay Back in 69 Days," *Facilities Design & Management*, June 1982, p. 13.

[9] This case study is based on Charles C. Benton and Marc C. Fountain, "Successfully Daylighting a Large Commercial Building: A Case Study of Lockheed Building 157," *Progressive Architecture*, Nov. 1990, pp. 119 -121; "Employees respond to Lockheed Building 157," *Professional Energy Manager,* July 1984, p. 5; "Lockheed's No. 157: Ex Post Facto," *Facilities Planning News,* October 1984; and personal communications with Lee Windheim and Don Aitken.

[10] The case study of West Bend Mutual is based on Paul Beck, "Intelligent Design Passes IQ Test," *Consulting-Specifying Engineer*, January 1993, pp. 34–38; and Walter Kroner et. al., *Using Advanced Office Technology to Increase Productivity* (Troy, NY: The Center for Architectural Research, 1992).

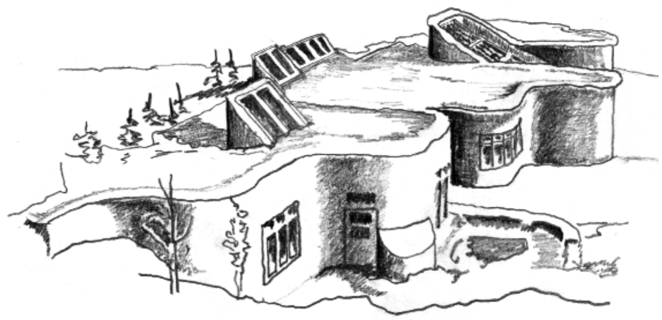
[11] The RPI researchers note: "Subjects were not informed that an analysis of their productivity was being conducted by the research team. . . . Since the company's productivity measurements were ongoing and were not specifically noted by the employees, we believe that worker's behavior was not affected by their participation in the study."

[12] This case study is based on the authors' design consulting for and analysis of the Eco-Mart, and personal communication with Tom Seay.

[13] This case comes from William Browning, "NMB Bank Headquarters: The Impressive Performance of a Green Building," *Urban Land*, June 1992, pp. 23-25; William Browning, "NMB Bank," *Progressive Architecture*, May 1993; and personal communication with Dr. Tie Liebe and Anton Alberts.

[14] Olivier, David, *Energy Efficiency and Renewables: Recent Experience on Mainland Europe* (Energy Advisory Associates, Herefordshire, England, 1992), pp. 27, 28.

[15] Olivier, David, *loc. cit.*, pp. 27, 28; and Vale, Brenda, and Vale, Robert, *Green Architecture: Design for an Energy Conscious Future* (Bulfinch Press, Little Brown and Company, Boston, 1991), pp. 156-168.



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