Greening the Building and the Bottom Line: Increasing Productivity Through Energy-Efficient Design

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Many elements of energy-efficient building and office design offer the possibility of increasing worker productivity. These include but are not limited to improved lighting, heating, and cooling. An increase of one percent in productivity can provide savings to a company that exceed the entire energy bill. Establishing the link between energy-efficient design and productivity could therefore provide a powerful incentive for efficient design practices.

This paper will document several cases in which efficient lighting, heating, and cooling have measurably increased worker productivity, decreased absenteeism, and/or improved the quality of work performed. These cases show that productivity gains from energy-efficient design can be as high as 6% to 16%, providing savings far in excess of the energy savings. They also show that efficient lighting in particular can measurably increase work quality by reducing errors and manufacturing defects.

Comparisons with the few similar cases in the literature identify the design changes that are most responsible for increased productivity and quality. All of the cases examined here involve design changes that were already very cost-effective because of the energy savings. Therefore, efficient design may be one of the least expensive ways a business can improve quality and productivity.

Introduction

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%. This type of return is well beyond the "hurdle rate" of most financial managers. In addition, the same retrofit may cut energy use by 50¢ or more per square foot, which has significant positive effects on the Net Operating Income of a building. However, the energy and operating costs of a building are small when compared to the cost of employees.

What does a building cost to operate per rentable ft^2-year (noting that some of the categories in the graph above subsume others)? Based on a national survey of the stock of offices for 1990[1]' as summarized in the graph above, electricity typically costs ~$1.53 (85% of the total energy bill); repairs and maintenance typically add another ~ $1.372; both contribute to the gross office-space rent (including all utilities and support services) of $21 per square foot. Yet paying the officeworkers costs ~$130.3 Thus the officeworkers' salaries cost ~72 times as much as the energy costs. Or, an approximately 1% gain in productivity is equivalent to the entire annual energy cost (Figure 1).

Gains in productivity can come through better use of time, fewer distractions from eye strain or poor thermal comfort, and similar factors. Productivity is measured in production rate, quality of product (for example lower defect rates), and changes in absenteeism.

Work done at Western Electric in the 1920s and 1930s 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 experimenter. 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. Subsequent analyses have

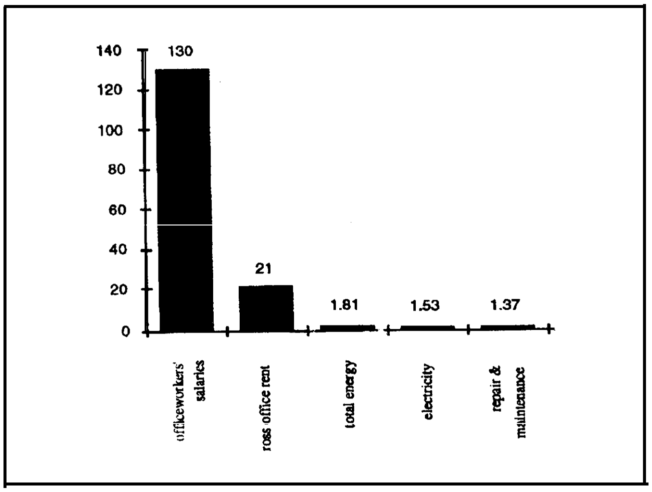

Figure 1. Approximate Operating Costs for an Office Building (1990 data $/rentable sq ft/yr, BOMA data except office workers salaries.)

called into question their experimental methods and results. 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. In any case, none of the real-life case described in this paper are anything like the contrived experiments done by the Hawthorne researchers.[4]

There is a crucial difference between designing for energy efficiency and energy conservation. Both lower energy consumption, however, conservation entails some level of curtailment of service-freezing in the dark. Energy efficiency must meet or exceed the quality of service that it replaces. The most efficient design typically focuses on giving users what they need, for example task/ambient lighting as opposed to a purely ambient strategy. It is important to reiterate that the goal of the companies in these case studies was to create energy efficient workplaces. The gains in productivity were for the most part an unanticipated effect. Some of the companies were aware that the measures implemented would improve the quality of spaces, however, the decisions to undertake the energy efficiency actions were based solely on projected energy and maintenance savings. In all the examples the measures of productivity had always been monitored by the companies. Additionally, none of the cases involved a change in management style.

Productivity Case Studies

The case studies presented here include retrofits of existing buildings and the design of new facilities. The retrofit case studies include: Reno Post Office, a lighting retrofit with a six year payback; Boeing's "Green Lights" effort which reduced its lighting electricity use by up to 90% with a 2-year payback—a 53% return on investment; Hyde Tools' implementation of a lighting retrofit with a one year payback; and Pennsylvania Power & Light upgrade of the lighting system in a drafting facility which produced 69% savings.

The case studies of new buildings include: Lockheed's engineering development and design facility that saved $300,000 to $400,000 a year on energy bills; West Bend Mutual Insurance's new building that has a 40% lower energy consumption than their previous facility, and used individual workstation controls; Wal-Mart's new prototype store, an experimental demonstration of energy efficiency and environmentally responsive technologies; and NMB Bank's new headquarters building that used 1/10 the energy per square foot of their previous building.

Retrofits

Reno Post Office. In 1986 the mail sorters at the Reno, Nevada main Post Office 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. Was this remarkable result due to the introduction of a new quality-oriented management initiative? Did some of the machine operators receive special training? Were they part of an experiment designed to boost productivity?

Not at all. In fact, the manager in charge of mail processing, Robert McLean, denies any personal responsibility for the improvement. McLean, now postmaster for Carson City, says, "We had the same people, the same supervisor, and I don't believe I was doing any motivational work." Yet he says that the data on the productivity and quality increase were solid: "It was irrefutable."

What happened? It began a few years earlier when the Reno Post Office was selected to receive a renovation that would make it a "minimum energy user." An architectural firm, Leo J. 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 chief architect, Lee Windheim, proposed a lowered ceiling and improved lighting (plus other energy-saving measures). With the new ceiling, the room would be easier to both heat and cool and, additionally, have better acoustics. The ceiling would be sloped to enhance the indirect lighting. The old, harsh direct downlighting would be replaced by soft, indirect lighting with more efficient and longer lasting bulbs. The energy-efficient room would be far more pleasant to work in.

Before starting the complete renovation, which would cost about $300,000, Windheim did a mock-up of the lighting and new ceiling. The idea was to let it run for a few months to see how it worked and how people liked it. The mock-up was done over only one of the two sorting machines. The graph 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 shot up more than 8%. The machine in the area with the old ceiling and lighting showed no change in productivity. A year later, as the graph shows, productivity had stabilized at an increase of about 6%. A postal worker operating the machine was now sorting about 1060 pieces of mail in the time it used to take to sort 1000.

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 a second later. If the operator keys in a zip code that doesn't exist, or no zip code at all, the letter will immediately be sent 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 intense that an operator can work a maximum of 30 minutes on the machine at one time before being replaced by another operator.

After the trial mock-up, the rate of sorting errors by machine operators dropped to one-tenth of one percent (0.1%)–only one mistake in every 1000 letters–the lowest error rate in the entire western region. As McLean tells it, "No one could poke holes in the story. " The data were "solid enough to get $300,000 to do the whole building." After the renovation, "People used to hang out there after work. It wasn't just the lighting, it was the whole impact on the work environment. But the lighting was the main thing."

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 with the new ceiling from reducing the recurring maintenance cost of repainting the underside of the exposed roof structure. 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. Working in a quieter and more naturally lit work area, postal employees did their jobs better and faster. The Reno Post Office not only became the most energy-efficient post office in the western region, as intended, it also became the most productive and error-free (Figure 2).

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. The changes to the building were designed solely to reduce energy use. Productivity had always been monitored. The increases in productivity were unexpected.

The story of the Reno Post Office has never been told before. Not long afterward, the post office was reorganized. Many individuals involved moved to other jobs or retired.[5]

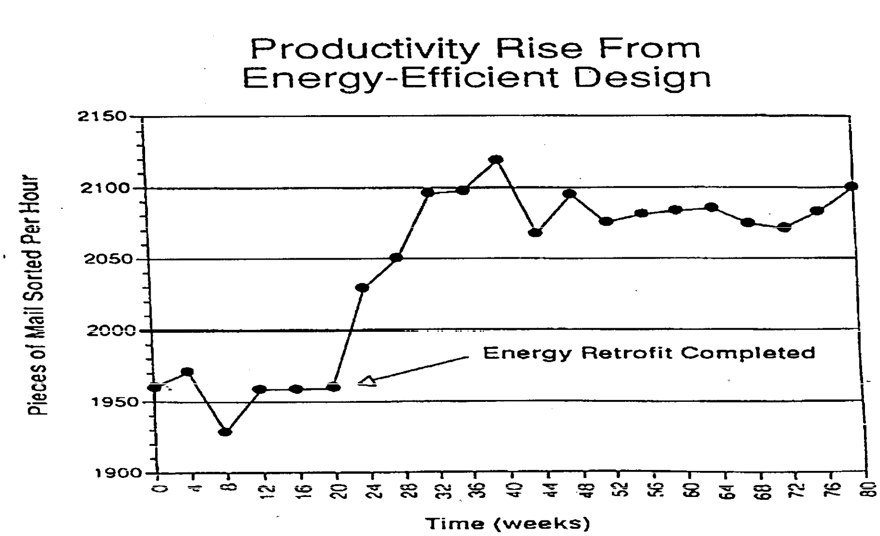

Figure 2. Productivity Rise From Energy-Efficient Design

Boeing. Boeing signed on to the Environmental Protection Agency's "GreenLights" program and reduced lighting electricity use by up to 90%, with a 53% return on investment. Lawrence Friedman, Boeing's conservation manager, notes that if every company adopted the lighting Boeing installed, "it would reduce air pollution as much as if one-third of the cars on the road today never left the garage." [6] However, Boeing discovered even more interesting results from their 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, said that previously she had been unable to see inside one part she had been working on and had been relying on touch alone. Now, for the first time in 12 years, she could actually see inside the part. One riveter reported that he'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. They don't break when a flying rivet head hits them.

The shipping and receiving area reported that quality was up: The number of packages sent to the wrong destination has been reduced.

Renton, Washington, is called the aircraft capital of the world because Boeing puts out up to 50 jets a month, 737s and 757s, in huge 500,000 square-foot plants. Some of those plants were in the middle of a lighting upgrade when visited in the spring of 1993. In some cases, where half the building had new lighting, half old. The difference was like day and night with crystal clear vision, with excellent color rendition on one side; fuzzy, distracting lighting on the other side. 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 side-wall panel for jets was moved from an area with old fluorescent into an area with high-efficiency metal-halide lamps. The shop would attach the panel to a stiffening member using numerous fasteners that leave a very small indentation in the panel. The old lighting provided poor contrast and made it difficult to tell if a fastener had been properly attached. The new lighting makes it far easier to detect imperfections, far easier to see whether there are indentations—and hence fasteners—everywhere there should be.

The new lighting improved by 20% the worker's ability to detect imperfections in the shop. The cost savings of catching errors when they happen is enormous. Friedman says that most of the errors in the aircraft interiors that used to slip through "weren't being picked up until installed in the airplane, where it is much more expensive to fix''—as much as several times more expensive. Even worse, "some imperfections were found during customer walk-throughs, which is embarrassing." Embarrassing and costly, because "the customer says, 'I don't like the way this panel looks,' and then you have to do a special order to match the interior of the customer's plane." Although it is difficult to calculate the savings from catching errors early, Friedman estimates that those cost savings alone exceed the energy savings.

DOE's Pacific Northwest Laboratory is now undertaking a detailed study of the long term results of the Boeing retrofit. In particular the study is investigating the cost savings from energy and from productivity and quality gains.

Hyde Tools. Hyde Tools, a Massachusetts-based, manufacturer of cutting blades, has 300 employees. Doug DeVries, purchasing manager from 1972 to 1992, notes that no amount of money saved will compensate for dissatisfied operators. He did a lighting upgrade from old fluorescent to new high-pressure sodium-vapor and metal-halide fixtures that cost $98,000 (including labor) with $48,000 covered by the local utility. He estimated that annual energy savings would also come to $48,000 (for a payback of about one year), but he still insisted in trying the upgrade in only one area to start. He left in the original fixtures in case workers wanted to change back after an agreed-upon six-month trial period.[7]

"For the first three weeks, a lot of people complained because the new lights cast an orange hue," said DeVries. "But when we experimented by turning the old fluorescent lights back on after six months, there was a near riot of disapproval." Why? For one thing, the new lights now made it possible to see tiny specs 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 lead 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.

Pennsyvania Power & Light. In the early 1980s, Pennsylvania Power & Light became increasingly concerned about the lighting system in a 12,775 square-foot room for its own 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."[8]

These veiling reflections "wash out the contrast between the foreground and background of a task surface—such as the lines on a drawing and the film on which they're drawn—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 bulbs and ballasts. Rather than just swapping out lamps in the old fixtures that ran perpendicular (North/South) to the work stations (East/West), 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, creating more variance in lighting levels which upgrades the appearance of the space."

With veiling reflections reduced, less light was needed to provide better seeing conditions. Russell believes this is a general principle: "As lighting quality is improved, lighting quantity often can 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 cleanup. 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, fixture cleaning and lamp replacement labor, and replacement ballasts."

The total net cost of the changes amounted to $8,362. Lighting energy use dropped by 69%, and total annual operating costs fell 73%, from $2,800 to $765. Lighting efficiency improvements lower heat loads, and therefore lower space cooling costs. The $2,035 a year savings would have paid for the improvement in 4.1 years, a 24% return on investment.

Under the improved lighting, productivity also jumped by 13.2 %. In the prior year, it had taken a drafter 6.93 hours 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." The productivity gain was worth $42,240 a year. In other words, "the annual saving derived from the lighting system change moves from $2,035/yr to $44,275/yr with energy savings, maintenance savings, and productivity improvement benefits having been specifically documented. This reduces simple payback from 4.1 years to 69 days." The productivity gain turned a 24% return on investment into a 540% return on investment.

"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% to 54 hours a year. "Improved employee morale also is noticeable." The better appearance of the space, reduced eye fatigues and headache, and the overall improvement in working conditions all helped boost morale.

Finally, supervisors reported that the new lighting has reduced the number of errors. Better lighting means better 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 per year." If this estimate were included in the calculation, the return on investment would exceed 1,000%.

New Buildings

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. In 1979, Lockheed Missiles and Space Company commissioned the architectural firm, Leo J. 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 as 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 love it. They consider it the building's most attractive feature. Other light-enhancing features include exterior "light shelves" on the south facade. These "operate as sunshades as well as reflectors for bouncing light onto the interior ceiling from the high summer sun," in the words of two researchers from Lawrence Berkeley Laboratory. "In the winter, the interior light shelves diffuse reflected light and reduce glare during lower winter sun angles."

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

The daylighting has saved Lockheed about 75% on its lighting bill. Since daylight generates less heat than office lights, the peak air conditioning load is also 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 $2,000,000 to the $50,000,000 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—a high return on investment. But the daylighting was part of a larger plan to boost worker productivity. The open office layout and a large cafeteria were designed to foster interaction among the engineers. At the same time, work stations were tailored for employee needs, including acoustical 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 responses as "representative of those encountered regarding the physical work environment":

"My work space," said Ben Kimura, staff engineer, "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." said Joanne Navarini, financial controller. "I think the building itself is very pretty; my own work station is very functional. I am five work stations 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."

Russell Robinson reported that "productivity is up" because absenteeism was reduced. Lockheed itself 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%." Aitken led numerous tours of Building 157 after it opened and was told by Lockheed officials that the reduced absenteeism "paid 100% 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% for the first major contract done in the building compared to previous contracts done by those Lockheed engineers. Aitken reports an even more astonishing anecdote: 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.[9]

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

The building has a number of energy-saving design features, including an energy-efficient lighting system (which includes task lighting and occupancy sensors), windows, shell insulation, and HVAC system. It uses a thermal-storage system that makes ice electrically overnight to help cool the building during the day. These measures allowed West Bend 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 features of the building are the Environmentally Responsive Work-stations (ERWs). Workers in open-office areas are given direct, individual control over both the temperature and air-flow. 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 of white noise levels (to mask out nearby noises). A motion sensor in each ERW turns it off if the worker leaves the space and brings it back on when he or she returns.

By giving workers direct control over their environment, the ERWs allow individuals working near each other to have very different temperatures in their spaces. No longer need the entire HVAC system 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 mock-up of the ERWs. Those workers who were most "outspoken" were allowed to test ERWs at their own desks.

The lighting in the old building had been provided by overhead fluorescent lamps, not task lamps. The workers in the new building all had task lights and they could adjust them with controls according to their preference for brightness.

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. The $0.84 per square foot savings—a 40% reduction—is 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 tenant questionnaire survey of workers' perceived levels of comfort, air quality, noise control, privacy, and lighting both before and after the move. "Subjects were not informed that an analysis of their productivity was being conducted by the research team."[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% 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% relative to productivity levels in the old building." The company's annual salary base is about $13 million, so even a 2.8% gain in productivity is worth about $364,000. The 2.8% figure almost certainly underestimates the actually benefit of the ERWs, according to Ronald W. Lauret, West Bend Mutual's senior vice president. 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% to 6%.

This case study has garnered a fair amount of attention. This attention has been almost exclusively focused 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 been due to the building design and systems.

Wal-Mart. In June 1993, a new prototype Wal-Mart store opened in Lawrence, Kansas. 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: The Center for Resource Management, William McDonough Architects, and the Rocky Mountain Institute, and focused on introducing a series of environmentally responsive design strategies and technologies.

Elements of this experiment include: the use of native species for landscaping; a constructed wetlands for site runoff and as 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 glazed arch at the entrance for daylighting, an efficient lighting system, an HVAC system that utilizes ice-storage, and a new type of light monitor (special skylights that control the way light enters the space) developed specifically for this project.

The "Eco-Mart" cost about 20% more than Wal-Mart's normal construction cost per square foot. Wal-Mart's normal costs are extremely low, and a building typically pays for its own construction cost in a few months. Several things account for the additional costs for this building: the sustainably harvested timber added 10% to the roof cost, the integration of systems was not optimized resulting in a more expensive cooling system, and the building contains elements not found in other stores. One of these is the light monitors. As a cost saving measure Wal-Mart decided to cut the number of light monitors to be installed in half. Rather than scatter the monitors across the roof, they were placed on only half of the roof, leaving the other half without daylighting.

The building had some kinks to work out. 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. The energy performance of the building was better than other Wal-Marts, but until the kinks are worked out, could be better. However, something else has gotten the corporation's attention. Each of Wal-Mart's cash registers are connected in real time back to the headquarters in Bentonville, Arkansas. This part of their effective "just-in-time" retail stocking and distribution system. According to Tom Seay, Wal-Mart's Vice President for Real Estate, this allowed them to discover, "... that the sales pressure [sales per square foot] was significantly higher for those departments located in the daylit half of the store."[12] This sales rate was also higher than the same department in other stores. Additionally, employees in the half without the light monitors are arguing that their departments should be moved to the daylight side. Wal-Mart is now considering implementing many of the "Eco-Mart" measures in both new construction and existing stores.

NMB Bank. In 1978, Nederlandsche Middenstandsbank (NMB) needed a new image, and a new headquarters in Amsterdam. According to Dr. Tie Liebe, head of Maatschappij voor Bedrijfsobjecten (MBO), NMB's development subsidiary, NMB wanted a building that was "... organic, which integrated art, natural materials, sunlight, plants, energy conservation, low noise, and water."

An integrated design team worked across disciplines-architect, construction engineer, landscape architect, energy expert, 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 ft^2 (50,000 m^2) building is broken up into ten slanting towers. The irregular S-curve ground plan has gardens and courtyards interspersed over the top of 301,280 ft^2 (28,000 m^2) 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, floor plates are narrow. Desks are located within 23 feet (7 meters) 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. Task lighting, custom decorative wall sconces, and limited overhead fixtures meet additional needs. The building has double glazing, as it predates high-efficiency "super-windows." 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 (100 m^3) hot water storage system, heated by a cogeneration facility, and heat recovery from elevator motors and computer rooms. Air-to-air heat exchangers transfer 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 between building design, daylighting and energy systems has yielded impressive results.

NMB's former headquarters consumed 422,801 BTU/ft^2 (4.8 GJ/m^2) of primary energy, the new building consumes 35,246 BTU/ft^2 (O.4 GJ/m^2) annually. In comparison an adjacent bank, constructed at approximately the same time and cost, consumes five times the energy per square foot.[13] Construction costs of *f* 3,000/m2 (*f* 987) or \$162 ft^2 (\$1991) include: land, structure, landscaping, art, furniture and equipment. Costs attributed to the energy systems were approximately \$700,000, however annual energy savings are estimated at \$2.6 million.[14] Dr. Liebe said "construction costs were comparable or cheaper than other office buildings in Holland." Using early 1980's technologies the energy measures had a three month payback. NMB has "... the lowest energy costs in Dutch office buildings, and one of the lowest in Europe."

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

Absenteeism among NMB employees has dropped and remained 15% lower than in their old building, Dr. Liebe attributes this to the better work environment of the new building. The building has done wonders for NMB's image, and "... NMB is now seen as a progressive, creative bank, and the bank's business has grown dramatically."[15]

Conclusion

The results of these case studies are worth summarizing. In the Reno Post Office, a lighting retrofit with a six year payback, resulted in a gain in productivity that decreased the facility's cost by more than the cost of the retrofit. Boeing reduced its lighting costs by up to 90%, with a 2-year payback—a 53% return on investment. In addition, the new, higher quality lighting reduces glare and helps Boeing reduce defects. Lockheed built an engineering development and design facility that saved $300,000 to $400,000 a year on energy bills–and productivity rose 15%. NMB Bank moved into a new headquarters building that used 1/10 the energy per square foot of their previous building, and cost no more than standard construction. The building was designed for daylighting, passive heating and cooling, and has 15% lower absenteeism than the old headquarters building.

The results of these case studies are impressive 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 improved visual acuity, thermal comfort and other factors 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. This is a point that seems to have been lost on many designers and building owners.

Clearly, there is a need for further research; however, the results of these few case studies indicates that the economic benefits of energy efficient design may be significantly greater than just the energy cost savings. This is a new opportunity for leveraging energy efficiency and improving the quality of life.

Endnotes

1. Building Owners and Managers Association (Washington DC), *Experience Exchange Report 1991*, at p. 95, showing national means for downtown 100-300,000-ft private-sector office buildings in 1990. Areas are net rentable space; income ($21) is for the office area only, *vs.* $16.68 for the entire building including retail space, parking, etc. The energy costs, and probably 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 >70 million ft^2. The authors are grateful to BOMA for kindly making these proprietary data available.

2. Boma, *loc. cit.* Of this, 21¢ is stated to be for HVAC maintenance. That includes heating too, but does not count the HVAC portion of electrical (which total 7¢) or of unclassified repair and maintenance (25¢), nor any HVAC portion of the contracted-out 43¢ of repair and maintenance services, so it is probably a good approximation to the total internal-plus-contracted repair and maintenance cost just for space cooling and air handling.

3. The *Statistical Abstract of the United States 1991*, Table 678, p. 415, gives 1989 average office salaries whose weighted average was $27,939/yr. We nominally adjust this by 4. 12% for 1989-90 monetary inflation (implicit gnp real price deflator) and add an estimated 20% for taxes and benefits, then divide by the boma 1990 national average of 268 ft^2/officeworker in 100,000-300,000-ft^2 office buildings.

4. 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 the traditional view of the Hawthorne Effect that the workplace environments effects productivity only because it signals management interest in the worker—is very different from what the Hawthorne researchers themselves concluded from their work: that productivity can be enhanced by a more cooperative

relationship between management and labor, and 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.

5. The Reno Post Office case was developed from personal communications with Lee Windheim of Leo J. Daly, and Robert McLean of the US Postal Service.

6. The discussion of Boeing is based on a visit to some of their Washington State buildings, personal conversations with Larry Friedman and Steve Cassens, articles in *Boeing News* from May 10, 1991 and January 15, 1993, and 1992 EPA data on the Green Lights program. It should be noted that the local utility covers about 75% of the cost of Boeing's new lighting with rebates, which has sped up the payback. On the other hand, Boeing calculates the payback on the basis of the very cheap electricity available in the Pacific Northwest, about 3.5 cents per kilowatt hour, which is almost half the national average. Some companies pay three times what Boeing does for electricity, so lighting efficiency would be highly cost-effective for them.

7. The Hyde Tools story is based on the *TPM Newsletter*, January 1993, p. 7, and personal communication with Doug DeVries.

8. This case is based on Russell Allen, "Pennsylvania Power and Light: A Lighting Case Study, " *Buildings*, March 1982, pp. 49-56; "Office lighting retrofit will pay back in 69 days, " *Facilities Design & Management*, p. 13; and personal conversations with.

9. Based 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, and "Lockheed's No. 157: Ex post Facto" *Facilities Planning News*, October 1984, and personal communications with Lee Windheim and Don Aitken.

10. The discussion 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, "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 our design consulting for and analysis of the EcoMart, and personal communication with Tom Seay, Wal-Mart's Vice President for Real Estate.

13. Olivier, David, Energy Efficiency and Renewable: Recent Experience on Mainland Europe, Energy Advisory Associates, Herefordshire, England, 1992, pp. 27, 28.

14. Olivier, David, Energy Efficiency and Renewable: Recent Experience on Mainland Europe, Energy Advisory Associates, Herefordshire, England, 1992, pp. 27, 28. and Vale, Brenda, and Vale, Robert, Green Architecture, Design for an energy conscious future, A Bulfinch Press Book, Little Brown and Company, Boston, USA, 1991, pp. 156-168.

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