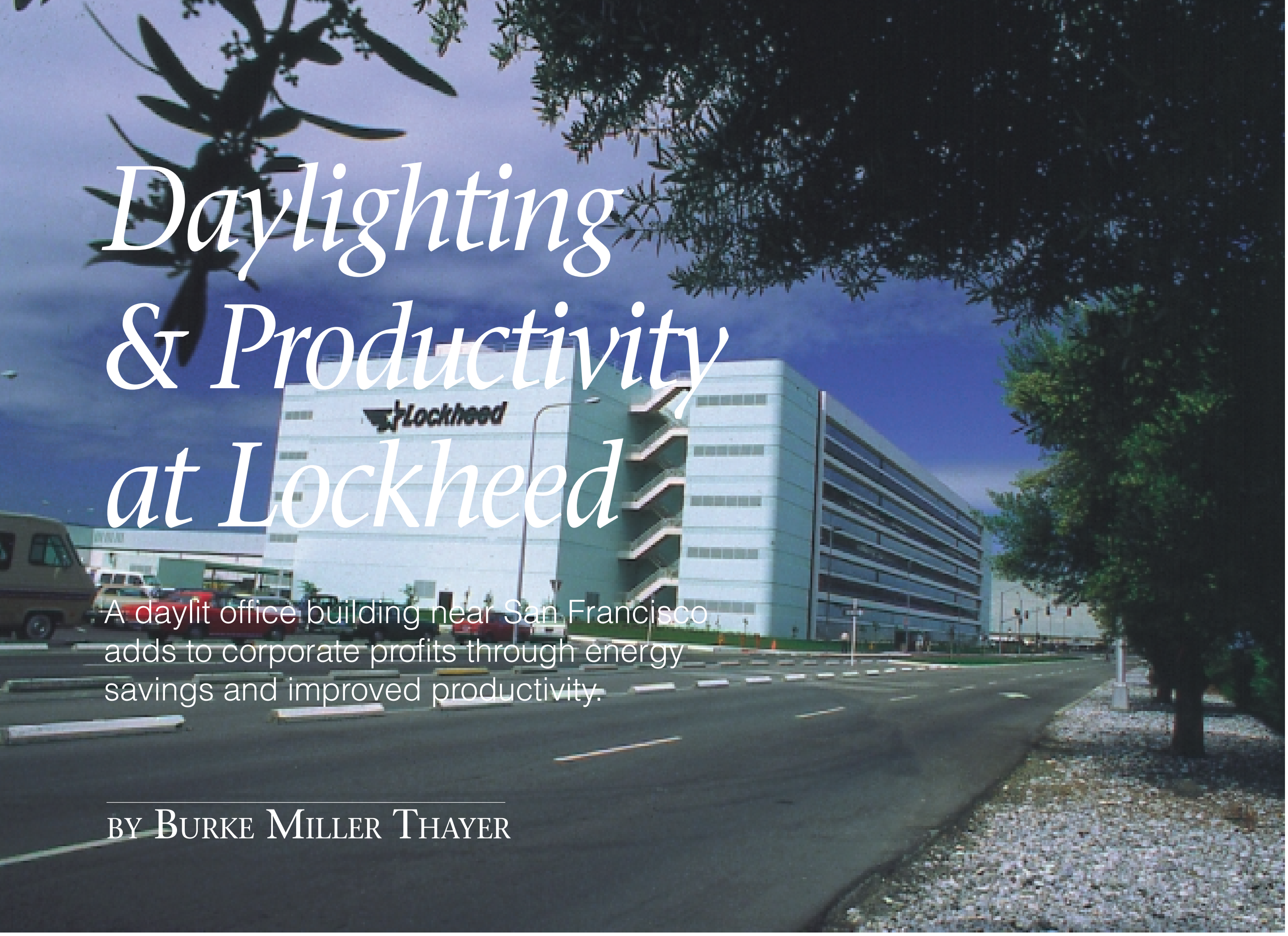
Daylighting & Productivity at Lockheed

A daylit office building near San Francisco adds to corporate profits through energy savings and improved productivity.

BY BURKE MILLER THAYER



Photography by Timothy Hursley

This daylit office building in Sunnyvale, California saves Lockheed Martin about $500,000 each year in energy bills. Higher employee productivity in the building, due largely to the daylighting design, saves even more.

In 1983, Lockheed Missiles and Space Company (now Lockheed Martin) moved a team of engineers and support staff into a new 585,000-ft^2 (54,300-m^2) building in their office complex in Sunnyvale, California. In their first year in "Building 157," they saved half a million dollars on energy bills and several times more due to reduced absenteeism and improved employee productivity. Possibly even more significant for their bottom line, the higher productivity of employees in Building 157 gave Lockheed a competitive edge that helped them win a coveted $1.5 billion contract.

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The key to Lockheed's good fortune is the building design itself. Soft daylight floods the interior. Standing in the central "litetrium," surrounded by trees, one gets the sense of almost being outdoors. Most importantly, though, the employees love it. They love where they work, and they are more productive because of it.

When Lockheed hired the architectural firm of Leo A. Daly to design Building 157, Lee Windheim, the project architect, predicted he could use passive solar daylighting design to cut the annual energy bills in half. But until they saw how the engineers responded to the new office environment, neither Lockheed officials nor the architects fully realized what a dramatic impact daylighting could have on productivity.

Design for the Climate

Building 157 sits in a sprawling complex of Lockheed offices near San Francisco, where the humidity is low and temperatures are mild. The winter lows rarely dip below 40°F (4°C). And although the temperature may reach 95°F (35°C) in the summer, it cools off quickly in the evening. Given this mild climate and high internal heat and humidity gains from lights and occupants, a large commercial building needs to lose heat and humidity to the outside most of the time. Therefore, the most energy-efficient insulation choice for the walls and roof was none at all, and the glass is all single-pane.

With virtually no heating load, lighting accounts for over half the energy demand in Bay area commercial buildings, and cooling and ventilating make up the rest. This energy profile gave Windheim the perfect opportunity to use daylighting design to save energy while pursuing his number one objective—to improve the work environment.

Deep Daylighting

All aspects of the daylighting design revolve around two simultaneous goals—to bring diffuse daylight deep into the office space and to eliminate direct sunlight and minimize brightness at the work sta-

High windows above the light shelves allow deep daylight penetration.

tions near the windows. The building layout and orientation, window placement, types of glazings, light shelves, ceilings and "litetrium" are all part of an integrated plan to achieve these goals. The architects carefully tested their design ideas with small-scale and eventually full-scale mock-ups before implementing them in the final building.

The five-level building is oriented about 15 degrees east of south. Each level has a 90-foot by 420-foot (27.4-meter by 128-meter) office area on the south and one on the north. In the middle is a 60-foot by 300-foot (27.4-m by 91.4-m) "litetrium," as

Small gains in productivity can make a huge difference in corporate profits.

the architects call it, which spans from the ground floor to the roof. At either end of the litetrium on each level is an additional 60-ft (27.4-m) square office area. Daylight enters the building through glazing on the north and south walls and through the glazed cap at the top of the litetrium.

The architects eliminated east and west windows in order to minimize heat gain and direct sunlight. Glass extends 15 ft (4.6 m) from floor to ceiling along the entire length of each office area on the north and south sides. The height of the glass coupled with the downward slope of the ceiling toward the interior is the key to the deep penetration of daylight. Daylight entering through this glass supplies adequate ambient lighting up to 45 ft (13.7 m)—about 3 times the height of the glass—into the office space. The ceiling slopes from 15 ft (4.6 m) above the floor next to the window to a 10-ft (3-m) height at 45 ft (13.7 m) in. It then slopes back up to 15 ft (4.6 m) at the edge of the litetrium (see building cross section, page 29). The slope of the ceiling helps to intensify the penetrating daylight by gradually decreasing the distance from the reflective surface of the ceiling to the work space below.

Daylight entering the building reflects off the internal light shelves and the sloped ceiling to provide diffuse ambient lighting deep into the work areas.

Along the north and south perimeters of each level, a light shelf extends 12 ft (3.7 m) into the office space at about a 7.5-ft (2.3-m) height. The 6-ft (1.8-m) span of glass above the light shelf is clear to allow as much daylight to enter as possible. Light coming through the glass bounces between the highly-reflective top surface of the light shelf and the ceiling as it penetrates farther into the building (see section view, page 29). On the south side, exterior light shelves extend 4 feet (1.2 meters) out from the building at the same height as the interior light shelves. Each exterior light shelf angles up and away from the building at about 30 degrees in order to reflect overhead sunlight into the interior space between the light shelf and the ceiling.

While they maximized the diffuse daylight entering the building, the architects were careful to reduce brightness next to the the north and south window areas and minimize direct solar heat gain from the south. To minimize heat gain from the south, a 2-ft (0.6-m) overhang shades the upper glass from direct summer sun, the exterior light shelves shade the glass below them and internal operable horizontal blinds cut out low-angled rays in the winter. On the north, where sky brightness from the high windows could be a problem for workers near the perimeter, the interior light shelves shade the work spaces below. The tinted glass installed between each light shelf and the floor below it blocks out about 60 percent of the light on the north and more than 80 percent on the south.

High ceilings allow daylight from the litetrium cap to penetrate about 45 ft (14 m) into the office space on either side of the litetrium. The cap has a sawtooth shape to it, with four rows of vertical clear north-facing glass alternating with sloped diffusing glass facing south. Light from the litetrium combines with light from the perimeter of the building to provide daylighting to the entire 90-ft (27-m) width of the office spaces on both the north and south sides. And although slightly more daylight reaches the areas nearest the south side, the daylighting levels are remarkably uniform throughout the building, with the "highest quality" (most even) light coming from north.

The "litetrium" in the center of the building creates an open, expansive feeling. Daylight from overhead provides ambient lighting for the surrounding office areas.

Integrated Electric Lighting

The Daly architects fully integrated the electric lighting system with the daylighting design to optimize the quality of light in the building. Instead of shining down from the ceiling, the fluorescent lamps point upwards and use the ceiling to reflect and diffuse their light and blend it with the penetrating natural light. The resulting illumination is both physiologically and psychologically optimal. Photocell sensors at the end of each light shelf measure the daylight levels and adjust the dimmable fluorescent lamps accordingly to provide an ambient brightness of between 30 and 35 footcandles.

Mechanical System

Building 157 is one of about fifty Lockheed office buildings connected to a central heating and cooling plant. When the building calls for air conditioning, chilled water circulates from the central plant through the building's air handling unit. About 80 percent of the time, the unit pulls air directly from the outside because the outside air is cooler and has less humidity than the air in the building.

Energy Performance

The architects ran computer simulations of their design for Building 157 in order to predict energy performance. Using a program (DOE-2.1) developed by the U.S. Department of Energy, they predicted energy use for combined lighting, cooling and ventilating of 20,000 Btu/ft^2/yr (454 million joules/m^2/yr). This is one-half the 40,000 Btu/ft^2/yr (227 million joules/m^2/yr) energy use specified in the 1980 California energy code for new commercial buildings in northern California. Although there are no records of actual energy use for Building 157 due to the nature of the Lockheed office park's central heating and cooling system, observers from the Lawrence Berkeley Laboratory have informally confirmed the predicted contribution of daylighting to the building's lighting load.

By incorporating daylighting features in Building 157, the architects not only reduced lighting loads—they reduced cooling loads as well. The daylighting cuts down on internal heat gain from electric lighting, thereby reducing the cooling load. (While daylighting can also be a source of heat gain, well-designed daylighting brings less heat with it per unit of illuminance than any electrical lighting source). According to Windheim, this dual reduction in lighting and cooling loads is why daylighting is such a successful energy design strategy for commercial buildings.

A Life-Cycle Gold Mine

To put the cost of a large commercial building in perspective, Windheim points out that a mere 2 percent of the total cost of Building 157 over its useful life (life cycle cost) will be for the initial design and construction. Another 6 percent will be spent on maintenance costs (including energy), and employee salaries will account for the remaining 92 percent. This is why the contribution of the building to employee productivity is the most important design consideration. Small gains in productivity can make huge differences in corporate profits.

The initial cost of designing and building the new Lockheed office was about $50 million. The architects estimate that the daylighting features, including advanced

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The ASES/PSIC Buildings for a Sustainable America Education Campaign is a nationwide effort to make policymakers, building professionals and consumers more aware of the benefits of applying sustainable energy principles to building design and construction. These benefits include increased affordability, more jobs, less environmental impact, reduced energy consumption and improved health.

Here's how Lockheed Building 157 stacks up:

Energy
50 percent overall reduction in total energy load

Affordability
Construction cost of $83/$ft^2$ (896/M^2)—about average for large office buildings in the San Francisco Bay area. The added cost for daylighting of $2 million is offset by energy savings of $500,000/yr. This translates to a simple payback of about 4 years or a 25 percent annual return on investment. The estimated savings due to improved productivity is in the range of $2 million or more per year.

Jobs and Economy
A portion of the money that Lockheed saves on energy is put back into the regional economy, which creates more jobs than if the money were spent on conventional energy supply. This is because conventional energy supply is one of the most labor-intensive industries.

Health and Productivity
By using daylighting, indoor trees and plants, continuous ventilation and optimal acoustic design the Lockheed building enhances the physical and mental well-being of its occupants. This contributes directly to employee productivity.

Environment
The Lockheed office complex is powered by a gas-fired power plant. Although natural gas combustion makes a relatively minor contribution to air pollution, there are other environmental costs associated with fuel exploration and production.

Lockheed Building 157 Project Details

Project Description: 3,000-Employee-Capacity Office Building
Owner: Lockheed Martin
Architect and Engineer: Leo A. Daly Company: Lee Windheim, AIA, Project Architect.
General Contractor: Hensel Phelps
Location: Sunnyvale, California
Size: 5-story, 585,000 ft^2 (54,300 m^2)
Construction Cost: $50 million
Date Completed: 1983
Heating Degree Days: 2439
Cooling Degree Days: 498

ENERGY PERFORMANCE

	Reference Case (California Code)	Building 157 (estimated)	% Reduction
Total	40,000 Btu/ft^2/yr (454 million joules/m^2/yr)	20,000 Btu/ft^2/yr (227 million joules/m^2/yr)	50 percent

HVAC: Variable volume HVAC system linked to central-complex heating/cooling plant.

DAYLIGHTING AND EFFICIENCY FEATURES

- Elongated plan, with long axis on east/west orientation for favorable north/south glazing exposure and daylighting control.
- Low shading-coefficient glass from floor to 7.5 feet (2.3 m) running full length of north and south exteriors on each level.
- 12-ft (3.7-m) interior light shelves running full length next to exterior glazing on north and south sides on each level. Clear glass above light shelves from upper surface of shelf to 6 ft (1.8 m) high.
- 4-ft (1.2-m) exterior light shelf on south side with angled reflective surface.
- Litetrium in center of building open from ground floor to roof with a cap of four "sawtooth" alternating rows of vertical north-facing clear glass and sloped south-facing diffusing glass.
- Sloped ceilings over north and south office areas on each level.
- No glazing on east or west.
- No insulation in walls or roof to facilitate loss of heat from internal sources.
- Fluorescent lighting with dimmable ballasts integrated with daylighting through photocell sensors.

ADDED COST OF SOLAR/EFFICIENCY FEATURES

Actual Cost of Building 157	$50,000,000
Predicted Cost of Reference	$48,000,000
Added Cost of Daylighting	$2,000,000

ENERGY COSTS

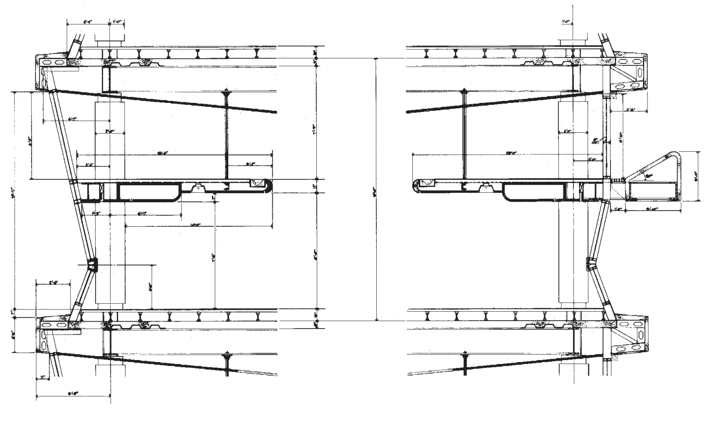
	Reference (estimated)	Building 157 (estimated)	Savings
Total	$1,000,000/yr	$500,000/yr	$500,000/yr

ENVIRONMENTAL/HEALTH FEATURES

- Continuous ventilation system
- Daylighting
- Plantings in litetrium and on all levels
- Sound dampening materials and glass angles

lighting controls, added about $2 million over what a conventional building of the same size and function would have cost. With overall energy savings of 50 percent (about $500,000), Lockheed recovered its additional investment in about 4 years. From a long-term investment point of view, the company is reaping a guaranteed annual return of 25 percent on energy savings alone.

In the case of Building 157, the energy savings, as impressive as they are, are overshadowed by the rewards of improved employee productivity. To illustrate this point, we'll assume that the average salary of the Lockheed engineers and staff is $50,000/year and that absenteeism (a simple measure of productivity) is down 15 percent (an unofficial figure attributed to company officials) from a level of 7 percent (14 days per year). A 15 percent improvement on 7 percent absenteeism yields a 1 percent improvement in productivity. Every 1 percent gain in productivity in Building 157 is worth $500 per employee ($50,000 salary times 1 percent), or $1.5 million ($500 times 3,000 employees) per year. This is 3 times the energy savings. And although these numbers are merely illustrative, Lockheed officials have privately acknowledged that their gains in productivity offset the $2 million dollar extra cost for the building in the first year of occupancy.



North Wall Section

South Wall Section

The Productivity Story

Of course absenteeism is only one among many ways to assess productivity. One could also assume that employees who find their building more enjoyable and comfortable to be in will exhibit more positive attitudes toward work and be able to concentrate more fully on their tasks. Every minute less of wasted time per hour represents a 1.67 percent gain in productivity. In Building 157, 2 percent more productivity means another $3 million in savings. And while impossible to confirm, even very small gains in productivity for companies like Lockheed can mean the difference between winning and losing major contracts with profits in the many millions of dollars.

Although it is difficult to document the impact of daylighting design on employee productivity, the story of Building 157 is a compelling one. When Joe Romm of the Department of Energy and Bill Browning of the Rocky Mountain Institute spoke with employees during a recent tour, they found that the engineers and support staff were, without exception, enthusiastic about their office environment. Although they praised many features of the building, including acoustics and aesthetics, the quality of lighting and the open, spacious feeling created by the central litetrium were at the top of their list.

The kind of praise reported by Romm and Browning and others supports Lee Windheim's firm belief that daylighting can have a major impact on productivity. According to Windheim, "Daylighting is the very best way to achieve both energy savings and a higher-quality office environment at the same time." Both of these achievements due to daylighting contribute to the bottom line of corporate profits. What's more, they contribute to a better environment and healthier employees. All told, daylighting is a design strategy that American companies and architects can no longer afford to ignore. ✪

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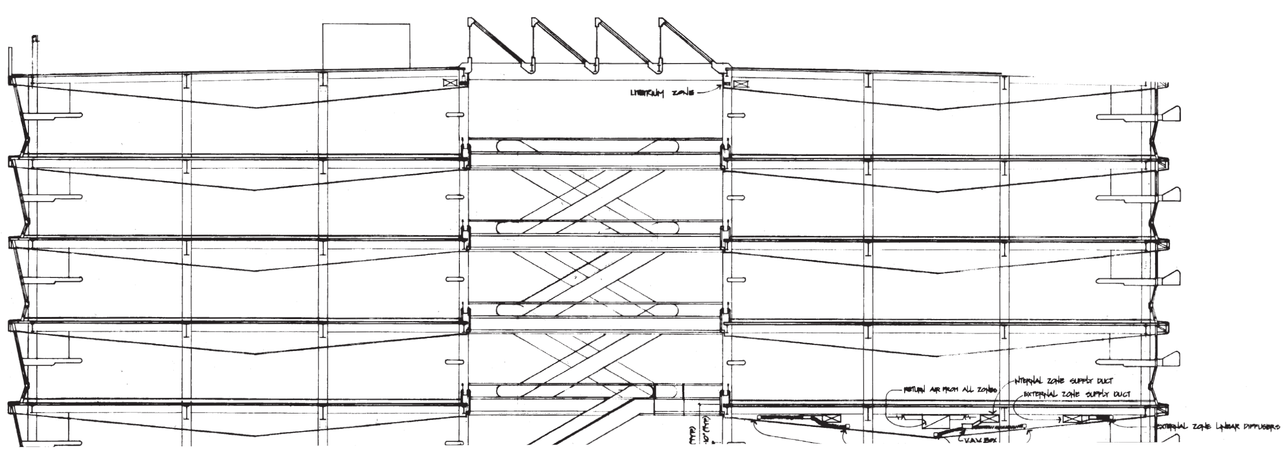
This is the seventh in a series of twelve SOLAR TODAY articles describing successful sustainable energy buildings throughout the U.S. The first six articles are available as a full-color reprint from the American Solar Energy Society. The series is part of the Buildings for a Sustainable America Education Campaign, co-sponsored by ASES and the Passive Solar Industries Council. This article was written for the Office of Building Energy Research, U.S. Department of Energy (DOE), through the National Renewable Energy Laboratory in Golden, Colorado, a DOE national laboratory.



Building Cross Section