Title

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Authors

Verderber, R.
Jewell, J.E.
Morse, O.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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R. Verderber, J.E. Jewell, and O. Morse

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Building Design: Impact on the Lighting Control System for a Daylighting Strategy

R. Verderber, J.E. Jewell*, and O. Morse

**Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720**

*** Pacific Gas & Electric Company
77 Beale Street
San Francisco, California 94106**

R. Verderber and O. Morse, Staff Scientists, Lawrence Berkeley Laboratory;
J.E. Jewell, Pacific Gas & Electric Company, San Francisco, California.

ABSTRACT

This paper discusses the unique features of a multistory office building that successfully permit most of the space to be daylighted and the electric lights to be dimmed by a cost-effective centralized system. This system includes: the use of light shelves, sloped ceilings, and proper building orientation and symmetry, and supplies only the ambient illumination. Measurements of the daylight illumination levels and the performance of the lighting control system indicate that daylighting can provide over 70% of the required ambient illumination through the year. Based on the installed cost of the lighting control system, its payback period is 2.2 years.

1.0 INTRODUCTION

The use of daylighting to illuminate a space should be integrated with the electric lighting system and generally requires sophisticated lighting controls for successful implementation. This is because daylight, being nonuniform and dynamic in nature, provides illumination that varies in intensity, both spacially and temporally. In most cases, for effective daylighting the lighting control system must be capable of dimming small sectors of interior spaces independently. This modular control requirement generally increases the initial cost of the control system. For such systems to be cost effective, they should also perform the other control strategies (e.g., scheduling, tuning, lumen depreciation, and load shedding).[1] This is particularly true in multistory buildings where only a small portion (10 to 15 feet from the outer envelope) can be adequately illuminated by daylight.

This report evaluates the potential cost effectiveness of the illumination system in a new building that has been designed to provide daylight illumination throughout its entire space. The unique design features of this structure permit integration of the electrical and natural lighting using a centralized dimming lighting control system and employing only one control strategy.

The next section describes these building features and how they distribute the daylight illumination in the space. The third and forth sections describe the lighting control system and the measurements made to determine its response to the available daylight. These features will be discussed with respect to the potential performance and cost effectiveness of the illumination system.

2.0 BUILDING FEATURES

2.1 Daylighting of Deep Interiors

In most multistory buildings only within about 15 feet of the windows the floor space can be suitably daylit. Figure 1 is a schematic cross section of the five-story building we studied, highlighting the features that permit the deep penetration of useful daylight illumination. The figure shows the interior light shelves on the outer envelope that beam the daylight inward. This feature, combined with the sloped ceiling and the central atrium, permit daylight illumination throughout the building's 90-foot width.

2.2 Building Position, Symmetry and Floor Plan

Figure 2 shows a typical layout of the floors. The length of the building along an east-west axis is about 400 feet and its width is 90 feet. Nearly all of the office space is contained in the north- and south-facing sections. The east and west sections have office space near the atrium, but they mostly contain service spaces, computer rooms, conference rooms and restrooms.

The floor is virtually all open-plan office space with 67 inch tall partitions. The five overhead rows of indirect lighting fixtures in the north and south sections and the daylighting need only provide the ambient illumination level of 35 fc. Desk and portable fixtures supply the necessary additional task illumination, which greatly simplifies the task of distributing the daylight throughout the entire space.

The building faces 20° west of south creating a daylighting illumination pattern that varies in the direction of the building's depth, but remains relatively constant along the rows of fixtures. Each of the five rows of fixtures that provide the ambient illumination (Figure 2) can be independently controlled to compensate for the different daylight levels. This aspect of the design permits the use of one controller for each row of fixtures.

2.3 Daylight Illumination Measurements

Extensive measurements of the daylight illumination in this building have been made for each season.[2,3] They have shown that the entire office area receives significant amounts of daylight illumination throughout most of the working day. Visual observations confirm that the illumination levels vary significantly only in the direction of the building's depth. Figure 3 is a plot of daylighting data taken for an entire day in May. The traces are at depths of 13, 42, and 77 feet from the exterior north and south walls. The 77-foot trace is 13-feet from the atrium. The daylight level is plotted for the third floor between 6 a.m. to 8 p.m. The daylight levels are plotted up to 100% of the target maintained illuminance levels (35 fc). The shaded areas represent the amount of illumination that should be supplied by the electric lighting to meet the design light level. The relative amount of illumination that must be supplied in each area during the day with the electric lighting is denoted by the percent in brackets, assuming the electric lighting could be dimmed 100%. For this ideal system the average illumination supplied by the electric lighting for the entire floor would be 28%.

3.0 LIGHTING CONTROL SYSTEM

The building's daylighting design features allow a centralized lighting control system to operate each row of lamps independently. The controller for each row responds to the output of photocells that are positioned beneath the light shelf or in the ceiling by the atrium (see Figure 5). Each lighting control unit dims about 48 lamps operated by energy efficient two-lamp core-coil ballasts. The installed cost of each control unit, including the photocell, was $850.00.

Measurements of the electrical performance of the entire system showed that the average power to each two-lamp system was 76 watts at full light output, including the power dissipated by the controller. Figure 4 is a plot of the data that shows the relationship betwen input power and light output. The lamps can be dimmed to 22% of full light output. The power at this minimum is 27% of full power, or 20.5 watts for the two-lamp system. This result shows that the power reduction is nearly proportional to the reduction in light output for this control system.

4.0 LIGHTING CONTROL SYSTEM RESPONSE TO DAYLIGHT

The actual response of the electric lighting control system to available daylight was obtained by measuring the daylight illumination level during the day without the electric lights. Immediately afterward, the electric lights were turned on and the power to each row of lamps was measured. Since the power to each row of lamps at full light output was known, the percent each row of lamps were dimmed could be determined using the curve in Figure 4. The results of the measurements for the third and fourth south floors are summarized in Figure 5, which shows the daylight illumination level and the position at which it was measured (beneath each row of lamps). The illumination level was measured above the partitions at a height of 67 inches. The relative reduction in power for each row of lamps is shown in the parentheses. This figure also shows the position of the photocells beneath the light shelf and on the ceiling by the atrium. The three rows of lamps nearest the external wall respond to the photocells beneath the light shelf, and the two rows of lamps closest to the atrium respond to one of the photocells next to the atrium.

The data indicate that the lighting system has not been tuned at this early stage of the building's operation. On both the third and forth floors, three areas of the floor have adequate daylight illumination (>35 f.c.), yet five of the rows of lamps that provide electrical illumination for these areas have been dimmed only 25%, or to 75% of full power (and 73% of full light output). Based upon the capability of the lighting control equipment, the expected response with proper calibration would find the lamps fully dimmed with the systems drawing 27% of full power. Only the row of lamps on the fourth floor next to the atrium was operating at the expected dimming level of 34% of full power.

5.0 COST EFFECTIVENESS OF CONTROLS

When the electric lights respond properly to the available daylighting, both the power demand and electrical usage will be significantly decreased. Based upon the available daylight illumination (Fig. 3), we can estimate the energy savings in order to determine the cost effectiveness of the control system.

We found that for an ideal control system responding to the available daylight, the electric lighting was required to supply 27% of the ambient illumination during the fourteen-hour day. However, since the decrease in power for the actual installed dimming system is not proportional to the decrease in light output, the average power to the lamps should be at 30% of full power, instead of 27% of full power. In addition, when the daylight illumination level is above 35 fc, the light system is still at 27% of full power. Figure 3 shows that for four of the six curves representing two-thirds of the floor area, this condition occurs for an average of eight hours per day. Therefore, the average power usage per day by the lighting will increase by 10%. That is, on two-thirds of the floor, for more than half of the day, the average power usage will be at 27% of full light output. Thus, the daily average power of the lighting system during 14 hours of operation will be at 40% of full power.

Table I lists the cost of the controls and the operating cost of the system, considering the energy saved by the available daylight. One noteworthy feature of the results is the low cost of the control system for this floor area ($0.443 per square foot). This is because each control unit operates a large number of lamps. Each unit controls the light levels over an area of about 2000 square feet. Secondly, during a substantial part of the day, including peak demand hours, the power demand density is reduced from 0.95 w/ft^2 to about 0.29 w/ft^2. If one considers only the areas in the north and south sections (360,000 square feet), the power demand is reduced from 342 kw to 104 kw, or a reduction of 238 kw. Finally, when the lighting system is properly tuned to the available daylight, the energy use will be reduced by 60% and the payback for the cost of the controls will be an attractive 2.21 years. Even if the energy savings is only 50%, the payback still less than three years. If such lighting control system would also turn off the lights at the times when daylighting provides all of the necessary illumination, the payback would be less than two years.

This evaluation does not take into account the additional building cost that are required to beam the daylighting into the interior. That is, the overhangs, sloped ceiling, light shelves, and other building features. The suitability of a low cost centralized dimming system is determined by the site location, the building symmetry and the use of daylight for ambient illumination which does not necessarily require increased construction cost. Thus, a less formidable daylit building design would limit the use of these controls to the space near the outer envelope, resulting in the same cost and savings per square foot.

6.0 CONCLUSIONS

This study shows that centralized lighting control systems can effectively be used in conjunction with daylight, to provide ambient illumination throughout the entire floor space of a multistory building. The success of the control systems depends upon the design of the building.

Additionally, this study indicates the need for monitoring the performance of lighting control equipment after installation to determine whether full benefit is being obtained by its use. If not, the measurements can identify the flaws and permit them to be corrected. In this particular study, the placement of the photocells and the control system calibration were not optimized.

After adjustments, this will be another good example of the effective use of daylighting.

ACKNOWLEDGEMENTS

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TABLE I: ECONOMIC DATA

CONTROL COSTS

Unit Cost Installed ($)	Number of Lamps Per Unit	Cost Per Lamp ($)	Cost Per Floor Area ($/ft^2)
850.00	48	17.71	0.443

OPERATNG COSTS

Annual Operation Time	Power Per Lamp	Annual Energy Use Per Lamp	Energy Cost Per Lamp @ $0.08/KWH	Energy Cost Savings Per Lamp For Average Saving* Of		
H	W	KWH/Lamp	($)	50%	60%	73%
4400	38	167.2	13.376	$6.69	$8.03	$9.76

* 100% Less the full power average of 50, 40, and 27%.

SIMPLE PAYBACK FOR ENERGY REDUCTION OF

50%	60%	73%
2.65 yrs.	2.21 yrs.	1.81 yrs.

FIGURE CAPTIONS

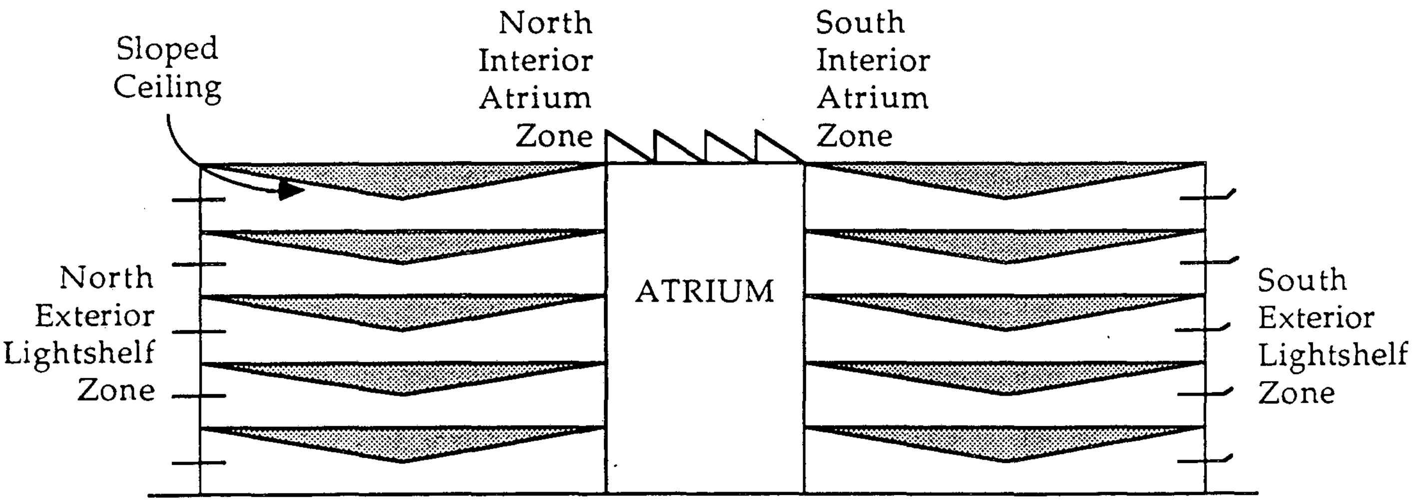
Figure 1: Cross section of five story building showing unique features, light shelves, sloped ceiling, and atrium.

Figure 2: Typical floor plan showing the ambient lighting system layout.

Figure 3: Daylight illumination levels during a working day in the north and South wings at three depths measured from the outer envelope or atrium.

Figure 4: Plot of the relative change in input power for change in the light output.

Figure 5: Relative decrease in the input power (parentheses) for rows of lamps and the measured daylight illumination levels on the south wing of the third and fourth floors.



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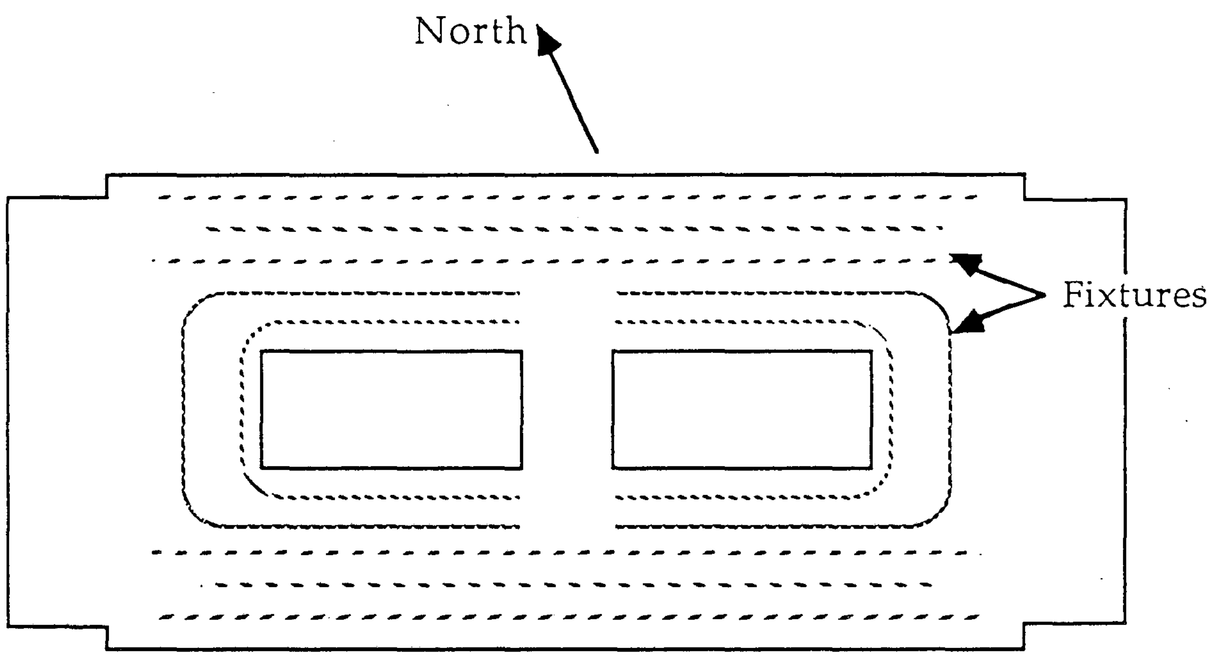

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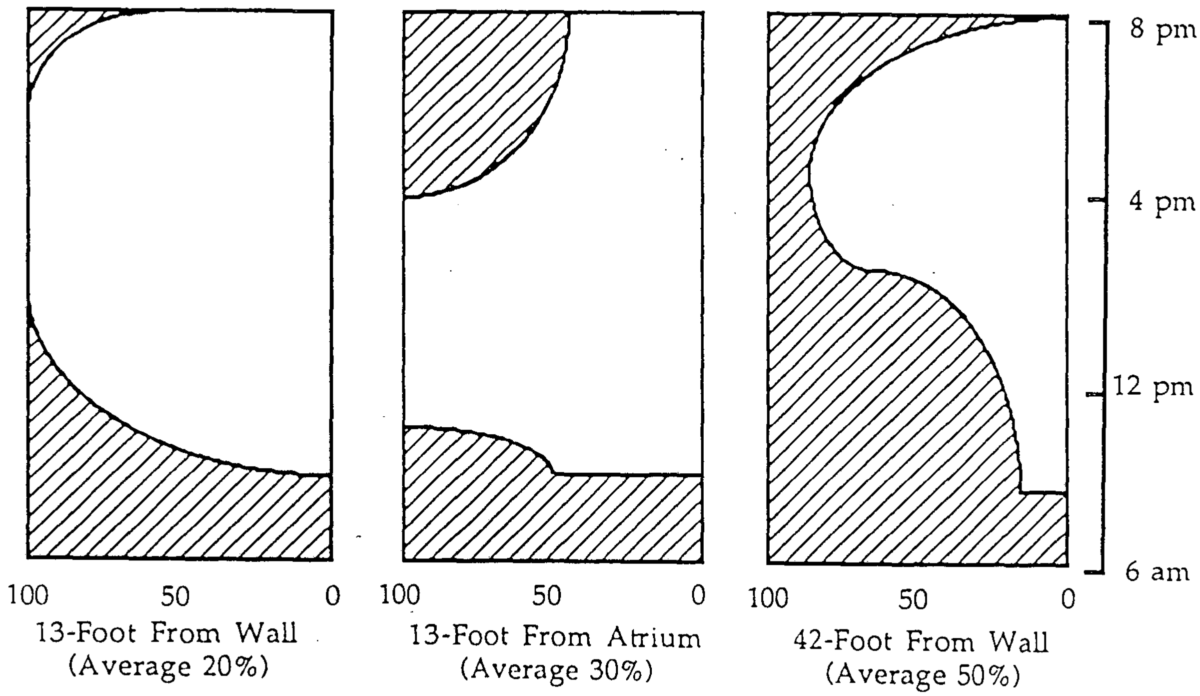
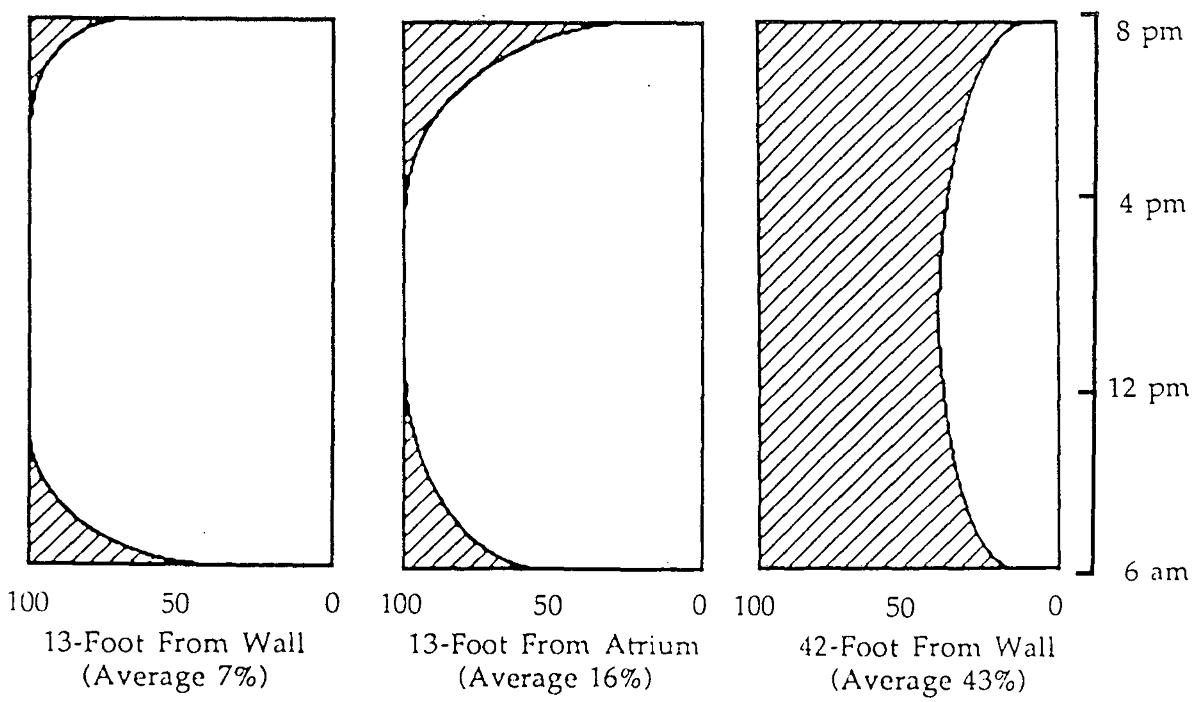
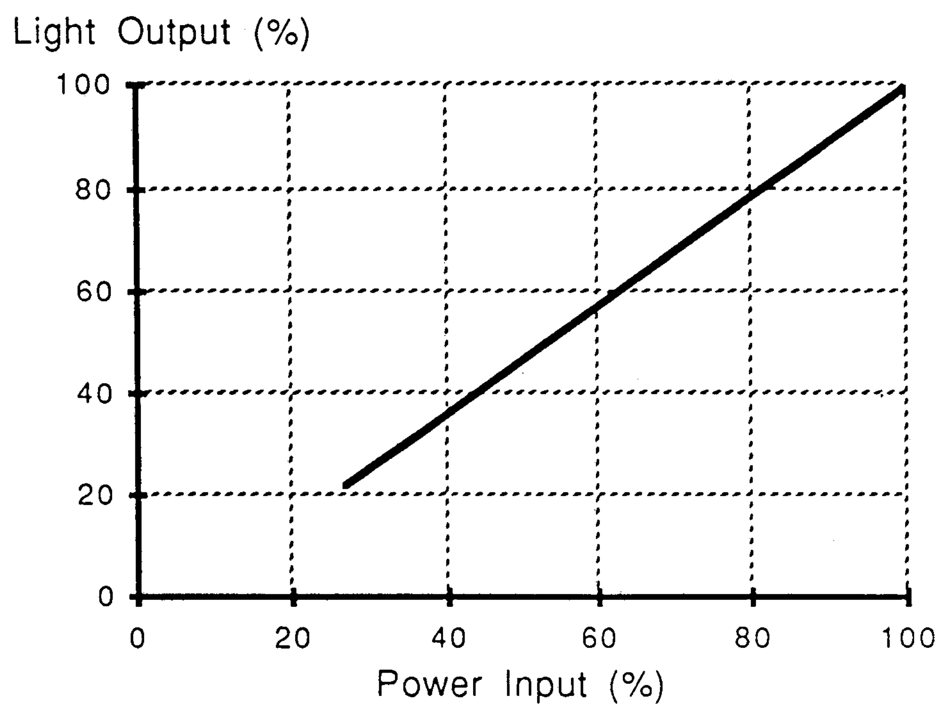


Relative Illumination Level (%) - South



Relative Illumination Level (%) - North

Figure 3: Daylight illumination levels during a working day in the north and South wings at three depths measured from the outer envelope or atrium.



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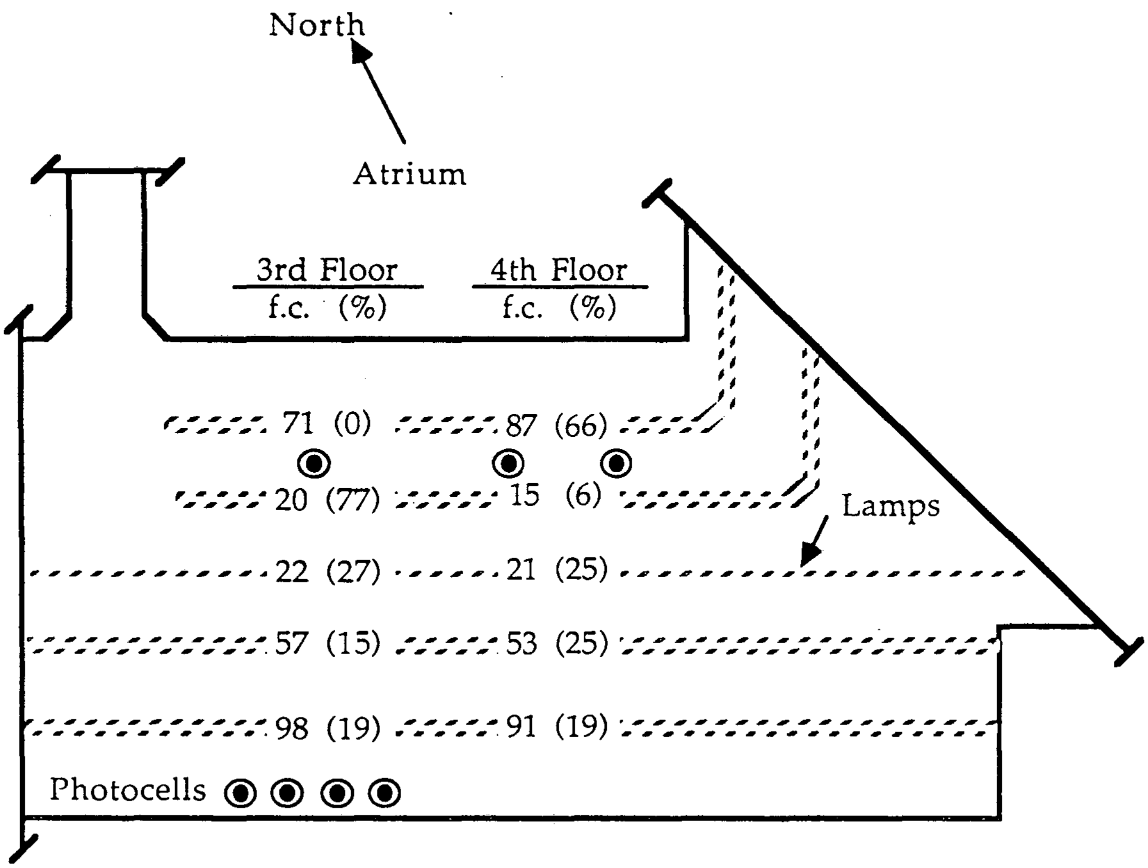

Figure 5: Relative decrease in the input power (parentheses) for rows of lamps and the measured daylight illumination levels on the south wing of the third and fourth floors.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720