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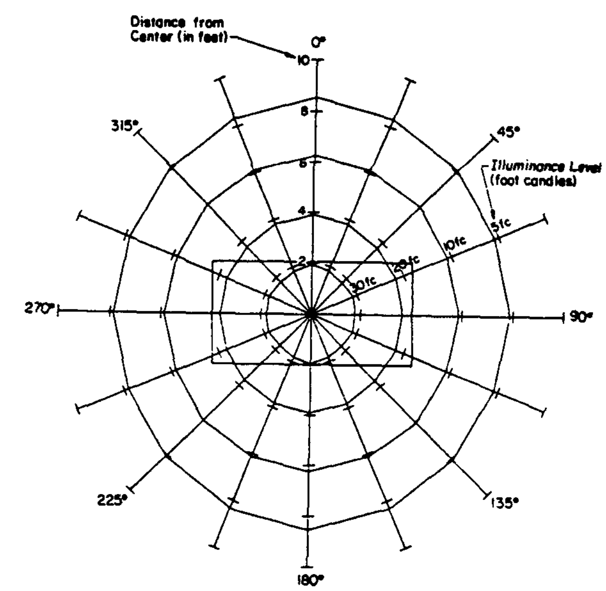
Performance of Specular Reflectors Used for Lighting Enhancement

by
Daiva E. Edgar

Since lighting accounts for about 20 to 30 percent of the total utility bill on Army installations, many installations try to lower lighting costs by retrofitting or upgrading to more efficient lighting systems. This study evaluated the effectiveness of specular reflectors used to enhance the effectiveness of two-lamp fixtures, which are claimed to enhance light levels of such fixtures by 50 to 100 percent, reducing the number of lamps required to light a given area.

Light levels and light distribution of two-lamp fixtures were measured before and after installation of specular reflectors to measure the change in lighting intensity, and to see if the use of reflectors changed the fixture spacing criteria. It was found that reflectors increased the ambient light levels from 9 to 34 percent, but did not increase the spacing criteria.

It is recommended that specular reflectors be considered for two-lamp lighting applications not constrained by maximum spacing criteria, where illumination falls below recommended or desired levels.



Illumination directly below fixture: 35fc

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Foreword

This study was conducted for Headquarters, U.S. Army Corps of Engineers under Project 4A162784AT45, "Energy and Energy Conservation"; Work Unit EX-XH3, "Lighting Technology Retrofits." The technical monitors were Samuel Baidoo, CECPW-FU-E and Robert Billmyre, CEMP-ET.

The work was performed by Energy and Utility Systems Division (FE), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was William Taylor. Special acknowledgment is given to Kevin Heyen, CECER-FE, for his help with the installation and removal of reflectors during the evaluation period. Don Fournier is Acting Chief, CECER-FE. Dr. David Joncich is Acting Chief, CECER-FL. The USACERL technical editor was William J. Wolfe, Information Management Office.

LTC David J. Rehbein is Commander and Acting Director, USACERL. Dr. Michael J. O'Connor is Technical Director.

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1 Introduction

Background

At Army installations, the lighting load accounts for about 20 to 30 percent of the total utility bill (W. Taylor and M.A. Dubravec 1990). Many installations upgrade lighting to more modern and efficient systems to lower costs. Retrofitting fixtures with specular reflectors is one possible lighting upgrade. Reflector manufacturers claim that light levels can be maintained by removing two lamps from a four-lamp fixture, installing a reflector, and relocating the remaining two lamps. Reflector manufacturers also claim that simply installing a reflector and maintaining the same number of lamps can almost double the light levels the fixture can provide. The performance of specular reflectors must be tested to verify whether these systems offer a practical and efficient alternative for use at Army installations.

Objectives

The objectives of this study were to test the effects of specular reflectors on the lighting levels and light distribution of two-lamp fluorescent fixtures, and to make recommendations regarding the use of specular reflectors in lighting retrofit or remodeling applications at Army installations.

Approach

Four reflector manufacturers were contacted and requested to design reflectors for luminaires in two group offices. Light levels and light distribution were measured for the selected fixtures. Each set of reflectors was installed in each room and measurements were again taken. Measurements were also taken with identical fixtures in an open area, with and without reflectors to evaluate lighting and distribution changes due exclusively to the reflectors. A written survey was distributed to occupants of the test room to gauge reactions and attitudes to the changed lighting. Conclusions and recommendations were drawn from an analysis and comparison of the lighting measurements.

Scope

The information from this report is meant to provide general guidance. Reflectors may perform differently as the room and furniture configuration changes. This is especially true in offices that use modular furniture, which uses room dividers that can shade and reflect light. Measurements were taken in this study using new fixtures, which are much shallower and direct more light out of the fixture than older fixtures common throughout Army installations.

Mode of technology transfer

It is anticipated that the information gathered in this study will be incorporated into a Public Works Technical Bulletin (PWTB).

2 Specular Reflectors

Types of specular reflectors

Reflectors are sheets of aluminum (in most cases), with or without a film, that are cut and bent into shapes that fit into luminaires. In general, there are two different processes of manufacturing: generic shaping, in which a reflector is made to fit many different luminaires; and custom shaping, in which a reflector is designed for a specific fixture. Generic shaping is much less common and usually does not have as good results as custom shaping. Custom designs require that a sample fixture or detailed fixture measurements be sent to the manufacturer so that the reflector can be designed for the fixture. The design is usually done using a Computer-Aided Design (CAD) system to determine the placement of each bend of the reflector to optimize light output from the fixture.

Reflectors typically have a total reflectivity of 85 to 95 percent, a large component of which is specular reflectivity. Standard white fixtures can have a total reflectivity of up to 88 percent, a large component of which is diffuse reflectivity. The difference between the two types of reflectivity is in the way the light reflects from the material. A material with a large component of diffuse reflectivity will disperse light in many different directions, while one with a large component of specular reflectivity will reflect the light in only one direction, making it useful in directing light.

The two main categories of reflectors are based on the reflective material used in their construction: anodized and polished aluminum, and silver film. Variations within these categories are common, e.g., one type of reflector has a mirror coating bonded to the base material. These broad categories of reflectors differ in their performance and prices.

Anodized and polished aluminum reflectors are usually less expensive than their silver film counterparts, but have a lower specular reflectivity (about 85 percent), which increases the amount of light lost during reflections. Because the aluminum does not scratch as easily as film coating, aluminum reflectors are usually recommended in areas that they may be exposed to large amounts of dust, steam, or other airborne impurities. Where maximum light output is not critical, aluminum reflectors are recommended for their lower price.

Silver film reflectors usually cost about $5.00 more per reflector than the aluminum ones. (Appendix A includes reflector prices current at the time of this study.) A silver film is adhered to a base of aluminum or steel for this type of reflector to give a reflectivity of about 95 percent. The film of these reflectors can be easily scratched and has the potential for eventual peeling or bubbling, making film reflectors less durable. These reflectors are ideal for use in generally clean areas where maximum light output is important.

The manufacturer of the mirror, or enhanced aluminum, reflector claims that this type of reflector has the durability of aluminum reflectors with the performance characteristics of the silver film reflectors. This reflector is manufactured by putting a mirror-like coating directly onto a base of aluminum. Since no film is used, the manufacturer claims that it is more durable than film reflectors and equal in durability to polished aluminum. The coating produces a reflectivity of about 95 percent—equal to that of the silver film reflectors. The cost of mirror reflectors is much higher (about $15.00 more per reflector). The higher price makes it difficult to achieve a reasonable return on investment, often a requirement for lighting upgrades and renovations.

Some companies also sell a film that can be applied to an existing fixture without a reflector. The disadvantage of using this film in a fixture is that the fixture is not designed to reflect the light out with a minimum number of reflections, like a reflector is. Therefore, there is no guarantee that the film will increase the fixture's efficiency.

A few companies also sell fixtures with built-in reflectors. The advantage of these fixtures is that lighting specifications are available for designing new lighting for renovations and construction. Table 1 lists the manufacturers surveyed.* Appendix A lists the types of reflectors, their manufacturers, reflector warranties, general information, and the prices of the reflectors that were tested.

Manufacturers' claims

A four-lamp to two-lamp retrofit

The most common claim that reflector manufacturers make is that, once a reflector is installed, two lamps can be removed from a four-lamp fixture, with no change in illumination levels. Manufacturers' test results support this claim. Independent studies by the Electrical Power Research Institute (EPRI) (March 1987), the National Lighting Product Information Program (NLPIP) (July 1992) revealed that,

* All Tables and Figures are at the end of the chapter in which they are cited.

in manufacturers' tests, post-retrofit measurements were taken after installing reflectors, and also after cleaning old, dirty fixtures and replacing old lamps with new ones. A more controlled test of reflector performance would have cleaned the fixture and replaced the lamps before taking the initial measurements of the unreflectorized fixture. The evaluation should show the initial illumination levels, without the effects of dirt and lamp lumen depreciation, which can lower light levels by up to 40 percent.

The EPRI study tested custom-made reflectors and luminaires with interiors lined with a specular reflective film for photometric performance, thermal performance, electrical performance, appearance, and component life. Results showed that fixture efficiencies changed from 56 percent for a four-lamp luminaire to 80 percent for the luminaires with either the reflectors or the silver film and two lamps. It was found that the performance of the silver film depended on the shape of the interior of the luminaire. The power used by the fixtures expectedly dropped from 164.3 Watts (W) for the four-lamp luminaire to 78.4 W for the retrofitted luminaires. The bulb-wall temperature dropped from 49 °C to 40 °C. The visual comfort probability went from 78 for the four-lamp fixture to 87 for the fixture with a reflector and 85 for the fixture with the silver film. The labor required to install the silver film made the total retrofit cost comparable to the cost of installing a custom-made reflector.

The NLPIP's Specifier Report on reflectors tested and evaluated nine aluminum, three mirror or enhanced aluminum, and 15 silver film reflectors in a four- to two-lamp retrofit. Power consumption of the fixtures was measured before and after the retrofit. Reflector material reflectance and fixture reflectance was measured before the testing. Luminaire efficiency and light distribution were also measured during the testing. Spacing criteria (SC),* average illuminance, illuminance uniformity, and vertical illuminance were tested in an application test of the reflectors. Visual Comfort Probability (VCP) is also evaluated. The spacing criteria for the original fixture was 1.3. The range of SC of the fixtures with the reflectors was 0.7 to 1.4. The average horizontal illuminance increased by 2 percent (to 18 percent) with the installation of the reflectors into fixtures that were delamped to two lamps. The average horizontal illuminance dropped by 35 to 44 percent from the original illuminance with the four-lamp fixtures. The VCP was 70 for a 20x20-ft room with an 8.5-ft ceiling and 64 for a 40x40-ft room with a 10-ft ceiling (1 ft = 0.305 m). The VCP changed from 68 to 77 for the first room and 62 to 69 for the second room.

* Spacing criteria is the maximum distance between fixtures that a manufacturer recommends for an even light distribution for a given fixture expressed as a ratio between the fixture spacing and the fixture's mounting. Anything that changes the light distribution has the potential to change the spacing criteria.

Light enhancement using specular reflectors

Another common claim made by reflector manufacturers is that light levels can be enhanced (or increased) by 50 to 100 percent by installing a reflector into a two-lamp fixture and keeping both lamps (sometimes repositioning them). If this claim were true, it might be possible to design new construction for a given light level, using fewer (reflectorized) fixtures.

Table 1. Surveyed manufacturers of specular reflectors.

Manufacturer	Address	Phone No.
ML Systems	165 Fieldcrest Ave Edison, NJ 08837	914/741-0400
Parke Industries	2246 Lindsay Way Glendora, CA 91740	714/599-1204
Dielectric Coating Industries	30997 Huntwood Ave Suite 103 Hayward, CA 94544	510/487-5980
Silverlight Corporation	16 W 151 Shore Ct. Burr Ridge, IL 60521	708/986-1651

3 Measurement of Light Distribution of Specular Reflectors

If reflectors can direct more light out of a fixture, it may be possible to design lighting for desired levels of illumination using fewer fixtures. This would only be possible if the light distribution from the reflectorized fixture is wider than the distribution of a fixture without the reflector. If the spacing criteria does not change, the number of fixtures may still be lowered if the fixture layout was constrained by insufficient illumination rather than spacing criteria. To evaluate these possibilities, the light distribution from fixtures with and without reflectors installed was compared.

Equipment

All tests used the following equipment:

Fixtures:	Lithonia model 2GT-232
Lamps:	Sylvania 3500K Octron (T8)
Ballasts:	Advance Electronic catalog # Rel 2P32RHTP
Light Meter:	Sylvania Model DS-2000.

Evaluation setup and procedure

One reflector from each manufacturer was installed in a luminaire in an unobstructed area so that the light distribution could be measured for each reflector. Measurements were taken at night so that illumination from other sources would not interfere with the evaluation. The fixture containing the reflector being tested was the only source of illumination in the room during the evaluation. The fixtures were run for at least 3 hours before measurements were taken to stabilize lamp and ballast temperature, which might affect illuminance measurements.

The illumination directly below the center of a fixture was measured using a Sylvania light meter, model DS-2000. Then the locations of points where the illuminance dropped by 5 footcandles (fc) were noted along the axes of 0, 22.5, 45, 67.5, and 90 degrees (1 fc = 10.764 Lumen/m^2). Since the fixture is assumed to be symmetrical, the measurements were extrapolated to cover the full 360 degrees around the fixture for general light distribution. Appendix B contains the measurement data.

The results of the measurements were then plotted using a spreadsheet. The resultant graph represents the light distribution of the fixture at a height of 30 in.—the average task height in most office applications (1 in. = 25.4 mm).

Results

Figures 1 through 5 show the distribution curves for the control fixture and the test fixtures. The distribution curves show that each reflector distributes the light a little differently. The most significant differences in the light distribution are at the center of the fixture. The fixtures containing reflectors had light levels much higher directly below the fixture than a fixture without the reflector. The perimeter readings did not change significantly. This shows that reflectors do direct more light out of a fixture, most of which is directed downward from the light fixture.

There is little difference in light distribution at the edges of the distribution curves at lower light levels. By the time that the lowest measurement of 5 fc was taken, almost all the distribution curves are the same. A difference of a few inches further out is not significant when compared to the total distance involved. Even at the 10 and 15 fc illumination points, the difference is still minimal.

The distribution curves and measurements indicate that the installation of reflectors will not change the illumination between the fixtures significantly. However, the illumination directly below the fixture will increase significantly. Therefore the spacing criteria is actually lowered and more fixtures would be necessary to maintain an uniformity of illumination throughout the room. If lighting levels are already at recommended levels, specular reflectors are not recommended since they will not save energy or reduce the number of fixtures necessary.

If the illumination level is the limiting criteria, it may be possible to reduce the number of fixtures. The increases in illumination varied significantly with the different reflectors, so a single fixture evaluation would be necessary to determine the increase in illumination and change in spacing criteria before the lighting design can be redone. It is important not to exceed the spacing criteria if uniform illumination is desired. This information is especially useful in new construction, and also in renovations where fixtures will be relocated or where the lighting systems will be replaced.

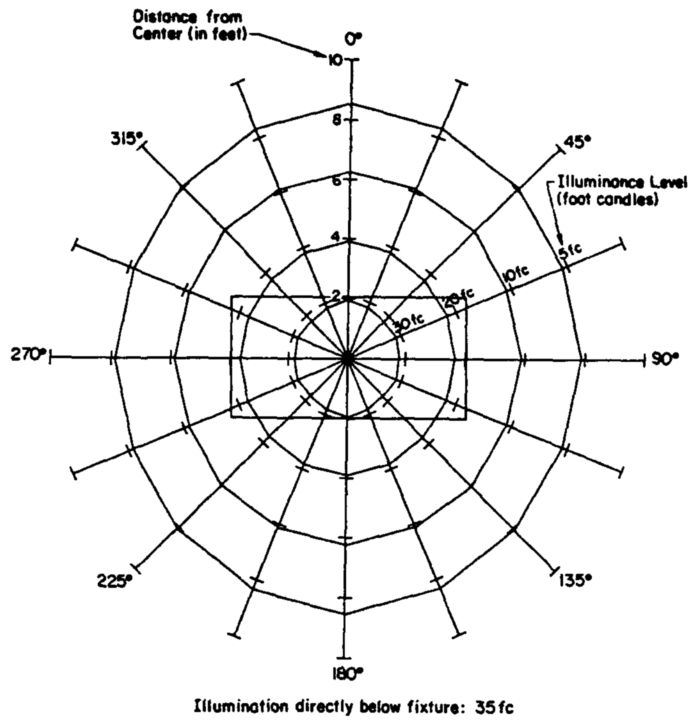


Figure 1. Light distribution from a fixture without a reflector. (Rectangle represents lighting fixture.)

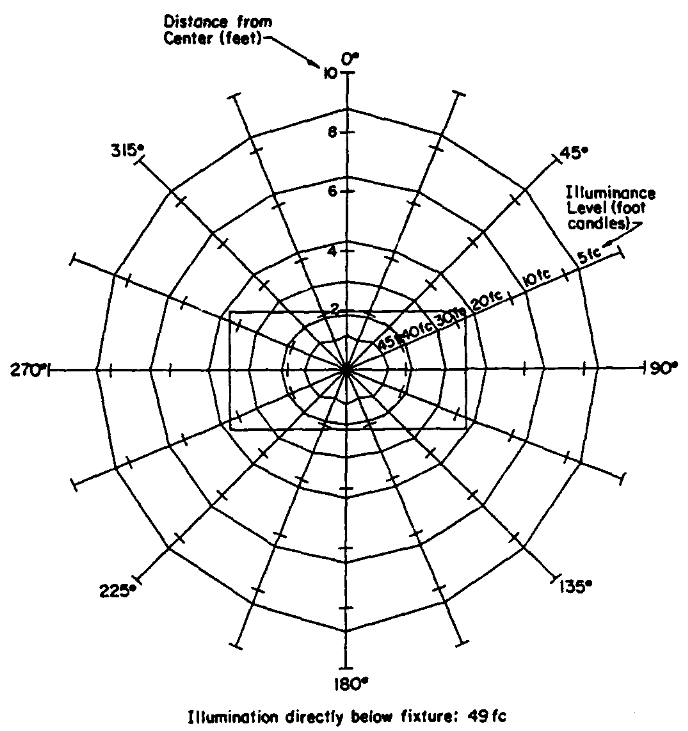
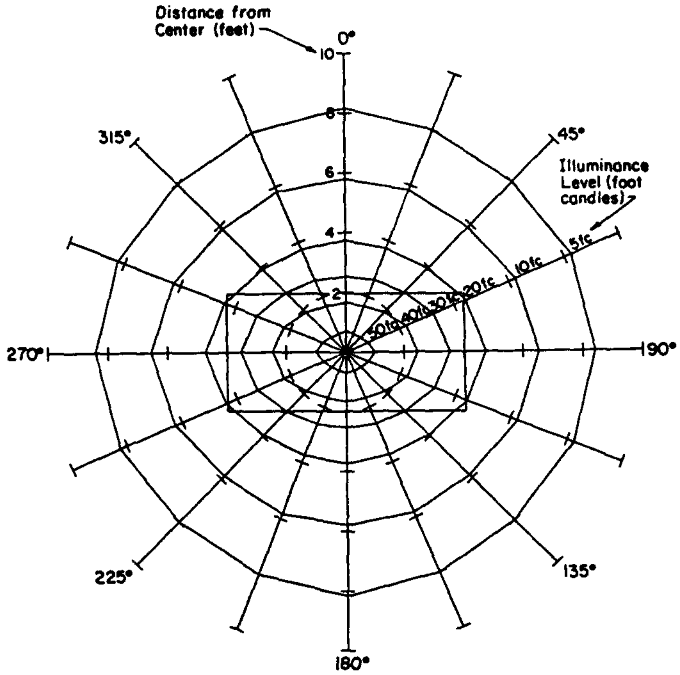
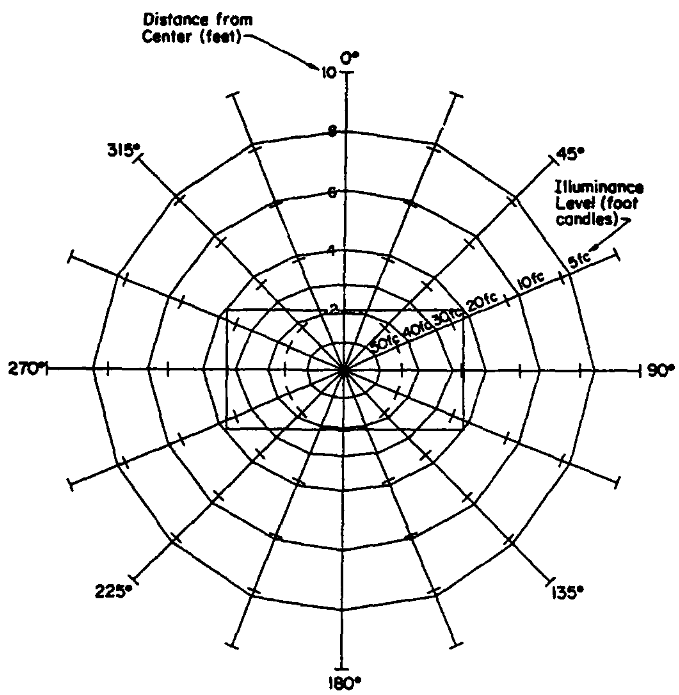


Figure 2. Light distribution from a fixture with a Parke Industries reflector.



Illumination directly below fixture: 52fc

Figure 3. Light distribution from a fixture with an ML Systems reflector.



Illumination directly below fixture: 54fc

Figure 4. Light distribution from a fixture with a DCI reflector.

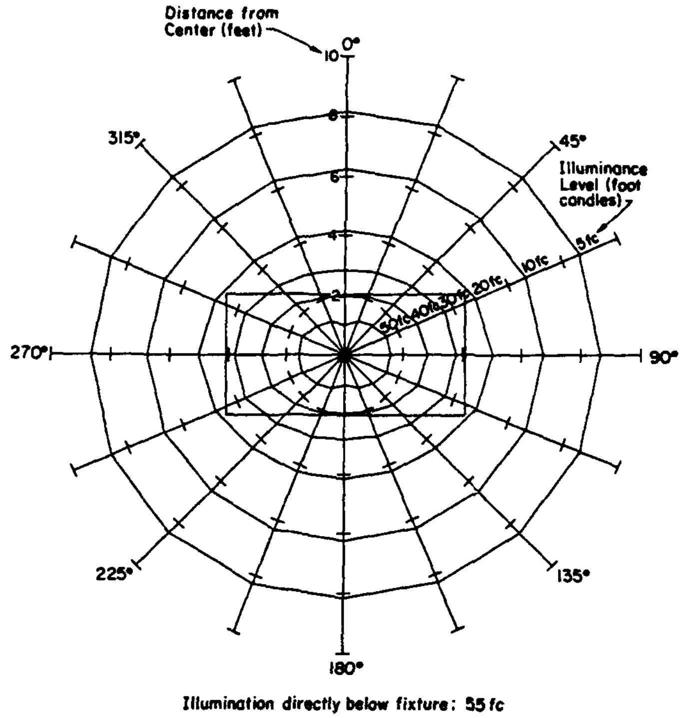


Figure 5. Light distribution from a fixture with a Silverlight reflector.

4 Field Evaluation of Light Enhancement Using Specular Reflectors

To evaluate the performance of light enhancement using specular reflectors in a practical application, reflectors were installed in two multi-person offices with different fixture layouts. Both rooms contained modular furniture that could affect different light distributions. Measurements were taken without changing the modular furniture setup. The results (actual measurements of illumination levels) may be different from those in an unpartitioned office area because the partitions reflect and block the light.

Procedure

Manufacturers were requested to design reflectors for a sample layout like that of Room A (Figure 6). A sample fixture was sent to each manufacturer for design. The manufacturers agreed to create a design that would produce an even light distribution. Since installations may want to order a large number of reflectors for retrofit to a number of similar rooms with different fixture layouts, the reflectors were also tested in Room B (Figure 7) to check for differences in performance due to small changes in a room's fixture layout.

Each set of reflectors was installed into the fixtures of both Room A and Room B. The fixtures and lenses were not cleaned and the lamps were not replaced in this evaluation because the fixtures were new when the testing began. A set of measurements was taken in each room using a Sylvania light meter, model DS-2000. The measurement points were taken according to the Illumination Engineering Society of North America (IESNA or IES) recommendations for average room illuminance, in Mark S. Rea, ed., *Lighting Handbook, Illumination Recommendations*, 8th ed. (IES, 1993). The average illuminance was then calculated (Tables 2 and 3). Appendix C shows footcandle readings for each set of measurements.

Occupants of the tested rooms were given written surveys in which lighting problems such as glare and lowered vertical illuminance (amount of light falling on walls) were addressed. General impressions were also requested. Appendix D lists the survey questions and the results.

The work spaces in each of the rooms are located almost directly below fixtures. This layout of the work spaces and fixtures assures maximum light falling on the work surface. To demonstrate this, measurements were taken of the illumination on each work surface in the rooms tested (Tables 4 and 5).

Results

The average room illuminance measurements showed that the reflectors increased the average illuminance of the rooms from 9 to 35 percent. The increases in Room A were significantly lower than those in Room B. A possible explanation of this may be that, since the fixtures in Room B were much closer to the wall, more light may have reflected off the walls than in Room A. Another reason for this difference may have been that, although both rooms had identical layouts of the modular furniture, the placement of the fixtures varied with respect to the location of the furniture. Because of this difference, light may have reflected off the partitions differently in each room with the Room B partitions directing more light toward the points where measurements were taken.

The measurements of work space illumination levels were much higher than surrounding areas. It is likely that the increases were greater because the measurements were taken almost directly below the fixture, in the area where the greatest increase in light levels would be expected. In Room A, the increases in illumination were between 29 and 47 percent, a significant increase, but greatly due to the fixture's location above the work spaces. The increases in Room B are even larger: between 54 and 98 percent, which lends support to some manufacturers' claims that light levels can be enhanced by 50 to 100 percent. These measurements were taken directly below the fixture. In surrounding areas, the increases were lower or even nonexistent as can be seen in the data in Table C1, Appendix C.

The surveys showed no problems with glare or vertical illuminance changes, and most occupants noticed no changes in the amount of light at their work surfaces, even though in some cases the light levels increased by 30 percent.

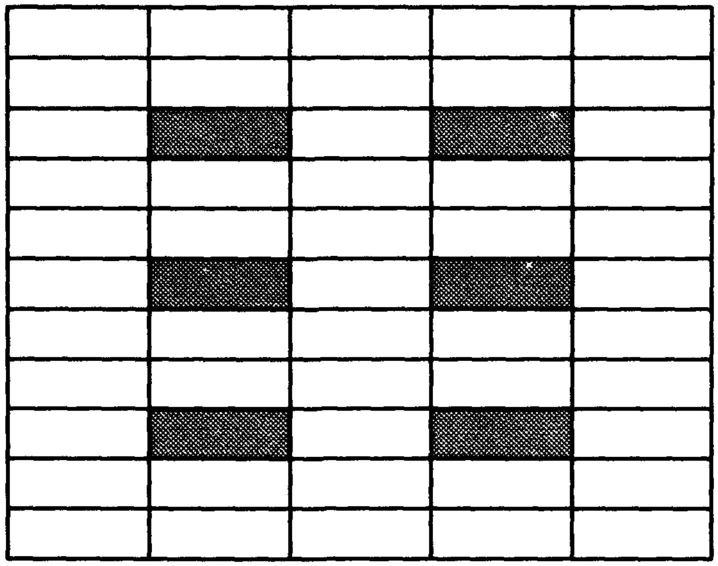


Figure 6. Layout of room A.

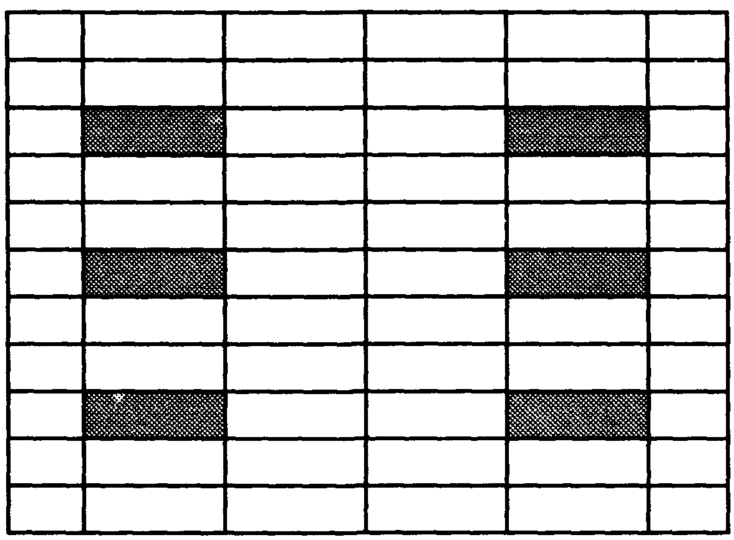


Figure 7. Layout of room B.

Table 2. Average illumination of room A.

Reflector Brand	Average Illumination	% Change in Illumination
No reflector	29.4	
Dielectric Coating Industries (DCI)	32.1	9
Silverlight	35.0	19
Parke Industries	34.3	17
ML Systems	32.0	9

Table 3. Average illumination of room B.

Reflector Brand	Average Illumination	% Change in Illumination
No Reflector	28.4	
DCI	34.5	22
Silverlight	37.9	34
Parke Industries	38.0	34
ML Systems	32.4	14

Table 4. Illuminance on work surfaces of room A.

Desk Number	No Reflectors	DCI	Silverlight	Parke Industries	ML Systems
1	23	34	31	30	29
2	23	31	26	23	27
3	30	50	46	44	36
4	33	48	43	44	40
5	39	55	52	57	59
Average	29.6	43.6	39.6	39.6	38.2
% Increase		47.3 %	33.8 %	33.8 %	29.1 %

Table 5. Illuminance on work surfaces of room B.

Desk Number	No Reflectors	DCI	Silverlight	Parke Industries	ML Systems
1	21	40	41	52	43
2	28	37	52	60	49
3	33	32	46	52	46
4	23	49	53	59	50
5	33	51	56	58	49
6	34	56	56	60	56
Average	28.7	44.2	50.67	56.8	48.8
% increase		54.1 %	76.7 %	98.3 %	70.3 %

5 Conclusions and Recommendations

This study tested the effects of specular reflectors on the lighting levels (illuminance) and light distribution of two-lamp fluorescent fixtures. Room occupants were also surveyed for their subjective response to the changed lighting. In written surveys, occupants of rooms where reflectors were tested did not report noticing any change in their lighting even though, in some cases, the light levels increased by 30 percent. Survey results indicated no problems or complaints involving glare or uneven light distribution.

The testing in this study used new fixtures, which are shallower and direct more light out of a fixture than older, deeper fixtures. In retrofits to such older fixtures, increases in illumination levels may be higher than the increases found in this study. Results showed that the reflectors increased the average illuminance of the two tested rooms from 9 to 35 percent. In Room A, work space illumination was increased from 29 to 47 percent, and in Room B, from 54 to 98 percent.

The apparently large recorded increases in light output were concentrated in the area directly below the light fixtures, and were not evenly dispersed throughout the room. This is an important consideration, since the purpose of overhead lighting is to maintain an even, general illumination level. This implies that specular reflectors maybe best for applications where lighting can be placed directly above work spaces, and where even light distribution is not a priority. In applications demanding flexible spaces, such as Army installation office settings, nonuniform lighting may increase costs associated with changes in lighting configurations demanded by each future change.

In installations that already use four-lamp fixtures, a simple retrofit of specular reflectors may appear to offer the double advantage of maintaining current lighting while cutting the required number of lamps (and energy expenditures) in half. In fact, retrofitting reflectors may not always be the best first alternative. It is recommended that installations considering a reflector retrofit should first evaluate the condition of existing lighting:

1. Current light levels should be measured and compared with IES recommended levels.
2. If the illumination levels fall below IES recommendations, the condition of the lamps and fixtures should be examined. A regular maintenance schedule can greatly benefit lighting levels. Dirty lenses should be cleaned and old lamps

replaced, to increase the fixture's efficiency and the amount of available light. Lenses soiled or yellowed beyond cleaning should be replaced. The light levels should be rechecked after maintenance.

3. If the illumination levels exceed IES recommendations, it is recommended to delamp all such fixtures to two lamps and disconnect one of the ballasts. Again, the light levels should be rechecked.
4. If the illumination still falls below the IES recommendations, specular reflectors and/or other retrofits may increase the illumination in the space.

In new designs, reflectors are not recommended if the design was done using two-lamp fixtures and the design is constrained by the maximum spacing criteria. If illumination levels of two-lamp fixtures are below IES recommended levels, then reflectors may be considered. The application of reflectors to specific fixtures should be tested before committing to a general program of retrofit or replacement.

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Uncited

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Appendix A: Reflector Manufacturers' Product Information

This is a list of the reflector manufacturers and the types of reflectors that were tested. Information about each of the manufacturers and reflectors evaluated is included.

Dielectric Coating Industries (DCI) (Omega Energy)

The DCI reflectors are designed specifically for a fixture. A fixture was sent to the company so that the reflector could be designed. The reflector consists of a mirror coating on the reflector backing itself. The manufacturer claims that no films are used in the manufacture of this reflector, so the reflector should last longer than a film-type reflector.

Installation of these reflectors was fairly simple. The lamps were removed and the reflector was installed into the fixture and secured with self-tapping screws. The raceway and the lamp holders remain in their original positions.

These reflectors have a 10-year warranty. Individual reflector cost was $45.00 for design and production.

ML Systems

ML Systems reflectors are specifically designed for individual fixtures and use a material called EverBrite, which is manufactured by ALCOA. EverBrite is a chemical-ly brightened and anodized aluminum and has a reflectivity of about 87 percent. ML Systems also recently began using a new film that is 95 percent reflective, but reflectors with that film were not tested. When asked how much difference that film could make, the salesperson said that the 95 percent reflective film would increase the total light output by about 20 percent over that of the 87 percent reflective aluminum. The 95 percent reflective film was claimed to have the same performance characteristics as those of Dielectric Coating Industries and Silverlight.

The ML Systems EverBrite reflectors consist of two pieces. Installation of the reflectors involved removing the lamps and ballast cover, removing and replacing the raceways, and relocating the lamp holders. Due to the more involved procedure, installations take longer, but reflector removal is easier since the new raceways serve as brackets for the reflector. This ensures exact placement of the reflector with respect to the lamps, and guarantees optimal performance.

The EverBrite lighting sheet is covered by a 25-year warranty by ALCOA, which excludes any fabrication or installation costs. Therefore, the materials of the reflector are guaranteed, but the defective reflector would be replaced with the equivalent amount of the lighting sheet, and not by another reflector. The literature gives no specific information about ML Systems providing a replacement reflector in the event of a problem arising. The cost was $22.30 per reflector for design and production.

Parke Industries

Parke Industries makes a reflector that comes in three pieces in which the center piece is removable so that the whole reflector does not have to be removed to gain access to the ballast. Parke Industries sells three different reflectors: a silver film reflector with 94 percent reflectivity, an aluminum film reflector with 85 percent reflectivity, and a polished aluminum reflector with an 82 percent reflectivity. All Parke Industries' reflectors are custom-designed. The salespeople usually help the buyer decide on the type of reflector that best suits the needs of the application. The reflector that was tested from this company is a silver film, three-piece reflector.

Installing the reflectors involved removing the lamps, ballast cover, raceways and lamp holders, and installing new raceways that relocate the lamp holders and serve as brackets for the reflectors. The center piece of the reflector serves as a ballast cover, so the original ballast cover does not need to be reinstalled. This center piece is listed with Underwriters Laboratories (UL) as a ballast cover. After the reflector is installed, the lamps are then put back into the fixture.

The only problem with the three piece reflectors is that, when removing and reinstalling the center piece to gain access to the ballast, it is nearly impossible not to scratch the silver film of the reflector. The film then tends to peel in the places where it was scratched. This should not affect performance of the reflector since the areas that get scratched are not visible when the reflector is fully installed.

Parke Industries provides a 10-year performance warranty that guarantees that the reflector will perform as stipulated for the warranty period. The cost for each reflector is $28.70 for design, production, and delivery.

Silverlight Corporation

Silverlight Sterling Silver Reflectors consist of a silver film manufactured by Courtalds Performance Films on aluminum. The silver film is treated with a patented antistatic inhibitor built into the top surface of the film. Therefore, the reflectors resist static and dust accumulation better than other reflectors of similar manufacture, according to the manufacturer. The reflectors were designed specifically for the fixtures and application. The reflectance of the reflector is about 95 percent.

Installation consisted of removing the lamps from the fixture and then securing the reflector to the fixture using self-tapping screws. Instructions were included for correctly situating the reflector with respect to the lamps within the fixture.

Silverlight provides a 5-year warranty covering the reflectors and installation. Significant loss of reflectivity or delamination are covered under the warranty. Reflectivity losses due to scratching are not covered. In the case that the reflectors are shown to be defective, Silverlight will cover the cost of materials, manufacture, delivery, and installation of replacement reflectors. The cost for each reflector was $29.50 for design, production, and shipping.

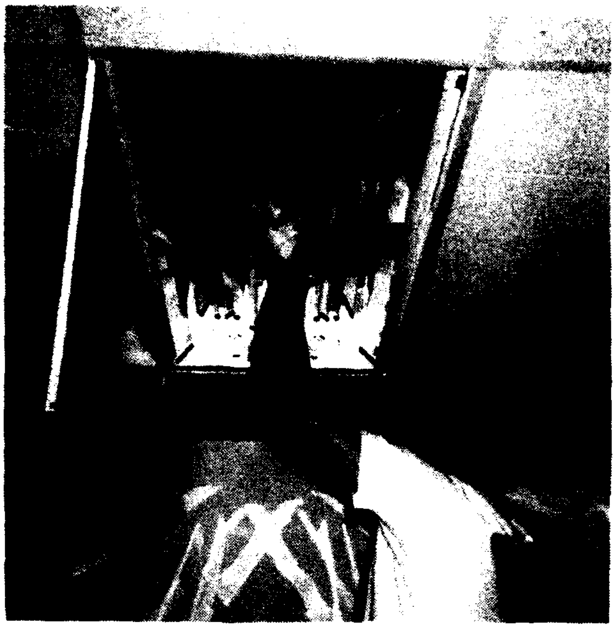

Figure A1. Reflector being installed.

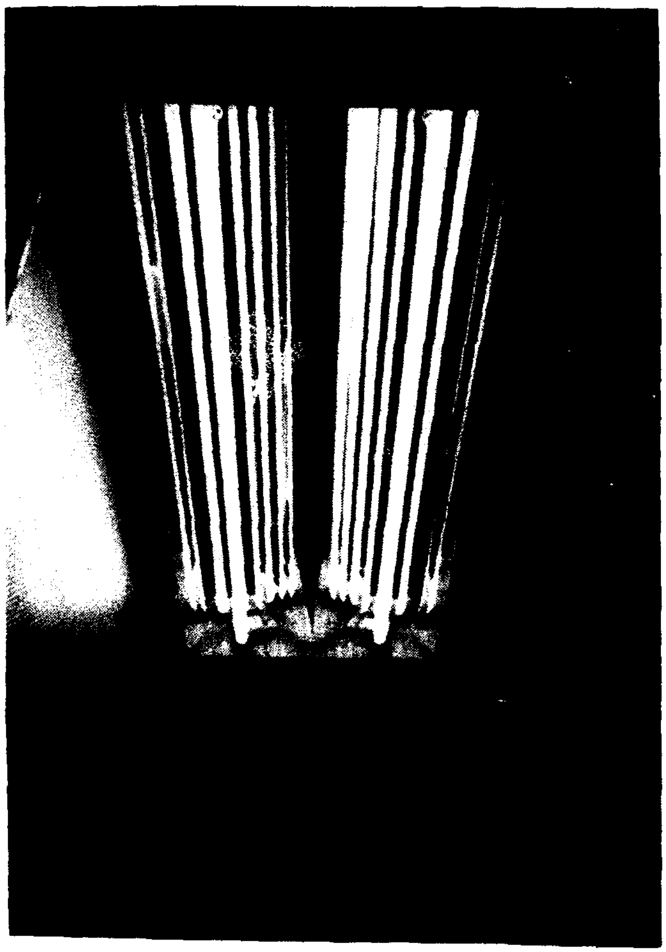

Figure A2. Installed DCI reflector with lamps.

Figure A3. Installed ML Systems reflector without lamps.

Figure A4. Installed Parke Industries reflector with lamps.

Figure A5. Installed Silverlight reflectors without lamps.

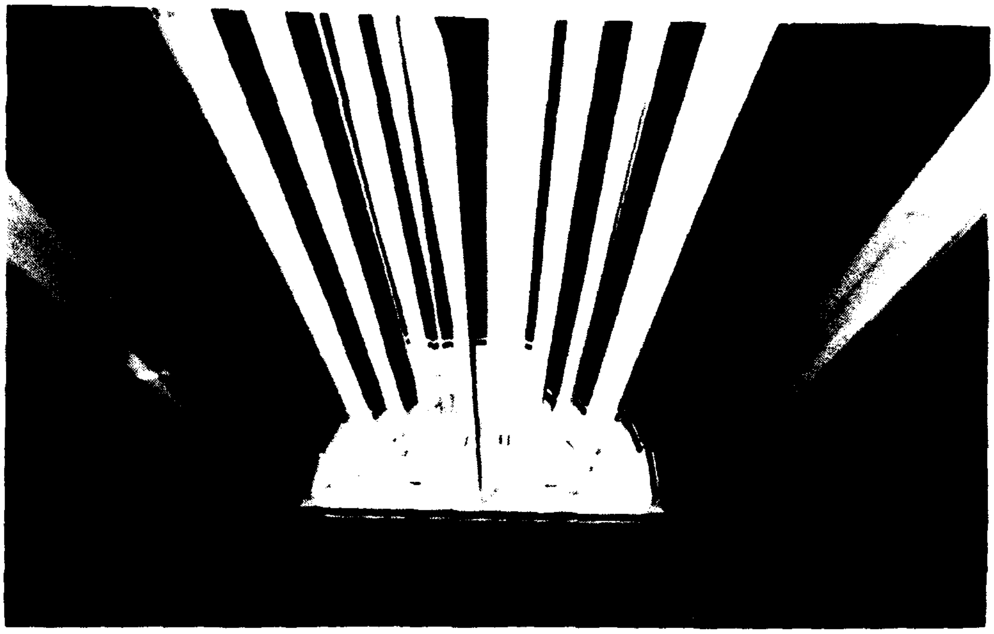

Figure A6. Installed Silverlight reflectors with lamps.

Appendix B: Distribution Measurements

Table B1. No reflector—distance from center in inches at given footcandle readings.

	Distance				
Footcandles	0	22.5	45	67.5	90
30	23.5	22	21	22	21.5
25	37	33.5	33	33.5	34
20	47	46	44.5	44	44
15	60	57	57	55.5	56
10	75	73.5	72.5	70	70.5
5	102.5	100	97	94	94.5

Table B2. Parke Industries reflector—distance from center in inches at given footcandle readings.

	Distance				
Footcandles	0	22.5	45	67.5	90
45	14	12.5	15.5	16	17
40	22	22.5	24.5	26	26.5
35	29	29.5	32	32.5	34
30	35.5	36	39	40	40
25	43	43	46.5	48.5	49
20	52	51.5	54	56	56.5
15	63	62.5	64.5	66.5	66.5
10	78	77	78	78.5	80
5	105.5	102	102	102	101.5

Table B3. ML Systems reflector—distance from center in inches at given footcandle readings.

	Distance				
Footcandles	0	22.5	45	67.5	90
50	8.5	8	8.5	10	12
45	14	15	17	19	22
40	20	20	22.5	27	29.5
35	24.5	25	28	32.5	36
30	30.5	31.5	34	39	42.5
25	37	38	40	45.5	49
20	45	45	47.5	53	57
15	54.5	55	57	62	66
10	69.5	70	70.5	75	78.5
5	98	96	96	99	101

Table B4. DCI reflector—distance from center in inches at given footcandle readings.

	Distance				
Footcandles	0	22.5	45	67.5	90
50	11	11.5	13	14.5	15
45	18	18.5	20	23	24
40	23	24	26.5	29	31
35	29	30	32.5	35.5	37.5
30	34.5	36	38.5	41	44.5
25	41	42.5	45	48.5	50.5
20	48.5	50	52.5	55.5	58
15	59	60.5	62	65.5	67.5
10	72.5	73.5	76	77.5	80
5	96.5	98.5	98.5	99.5	102

Table B5. Silverlight reflector—distance from center in inches at given footcandle readings.

	Distance				
Footcandles	0	22.5	45	67.5	90
50	12	14.5	16.5	19	19
45	19	20.5	23	26.5	27.5
40	23.5	25	28.5	32.5	34
35	28	30	33.5	38	40
30	34	35.5	39	44.5	45.5
25	41	43	46	51	53.5
20	50	51	53	58	60.5
15	61	62	64	67.5	69
10	75	76	77.5	80	81
5	98	99.5	101.5	103.5	104

Appendix C: Average Room Illuminance

Measurements and Calculations

All the measurements are located in Table C1. The formula used to calculate the average room illuminance was:.

$$\text{Average Illuminance} = \frac{R(N-1)(M-1) + Q(N-1) + T(M-1) + P}{NM}$$

Where:

N = number of luminaires per row

M = number of rows

R = the average for all RX where X is a number from 1-8, this is R' in Table C1

Q = the average for all QX where X is a number from 1-4, this is Q' in Table C1

T = the average for all TX where X is a number from 1-4, this is T' in Table C1

P = the average for all PX where X is 1 or 2, this is P' in Table C1

Appendix E shows the location of all these points.

Table C1. Average room illuminance.

	Room A Set Number						Room B Set Number					
Point	1	2	3	4	5	6	1	2	3	4	5	6
R1	53	69	73	54	72	69	52	69	76	48	72	64
R2	34	35	36	34	37	32	39	46	50	36	45	38
R3	30	39	42	30	41	36	16	22	21	18	21	19
R4	37	42	40	35	40	26	18	22	21	19	23	20
R5	43	62	62	44	60	60	44	60	66	43	61	63
R6	41	40	40	35	41	40	43	58	42	48	54	50
R7	36	45	45	37	46	42	19	24	24	19	26	23
R8	48	34	49	48	54	51	19	23	25	23	25	22
P1	20	20	24	18	18	22	30	30	19	28	35	26
P2	18	22	23	19	23	20	19	23	26	20	25	20
T1	19	19	23	20	22	19	31	31	43	31	39	26
T2	20	29	30	23	26	25	36	45	70	37	58	55
T3	27	24	27	24	27	21	27	43	50	30	46	22
T4	37	34	46	35	45	40	32	30	37	21	33	41
Q1	21	24	19	25	23	23	18	20	18	17	19	16
Q2	34	32	31	32	31	36	34	42	37	36	47	43
Q3	22	20	21	23	23	24	13	12	14	11	16	12
Q4	32	33	35	30	32	36	24	27	26	29	30	27
R'	40.25	45.75	48.375	39.625	48.875	44.5	31.25	40.5	40.625	31.75	40.875	37.375
P'	19	21	23.5	18.5	20.5	21	24.5	26.5	22.5	24	30	23
T'	25.75	26.5	31.5	25.5	30	26.25	31.5	37.25	50	29.75	44	36
Q'	27.25	27.25	26.5	27.5	27.25	29.75	22.25	25.25	23.75	23.25	28	24.5
N	2	2	2	2	2	2	2	2	2	2	2	2
M	3	3	3	3	3	3	3	3	3	3	3	3
Average:	29.708	32.125	34.958	29.375	34.250	32.042	28.708	34.542	37.917	28.375	37.958	32.375
% change		8.1%	17.7%	-1.1%	15.3%	7.9%		20.3%	32.1%	-1.2%	32.2%	12.8%
% change'		9%	19%		17%	9%		22%	34%		34%	14%

Room A: Set 1: No reflectors; Set 2: Dielectric Coating Industries; Set 3: Silverlight; Set 4: No reflectors; Set 5: Parke Industries; Set 6: ML Systems

Room B: Set 1: No reflectors; Set 2: Dielectric Coating Industries; Set 3: Silverlight; Set 4: No reflectors; Set 5: Parke Industries; Set 6: ML Systems

% change = average illumination change from first set of measurements without reflectors
% change' = average illumination change from seond set of measurements without reflectors (set 4)

Appendix D: Room Occupant Survey of Responses to Reflector Installations

As part of the reflector evaluation, occupants of the rooms in which reflectors were installed were asked to note any differences they noticed in the lighting after new installations. This was done to make sure that the reflectors did not cause eye strain due to increased glare.

None of the occupants reported any change in glare from the reflectors. Some felt that the rooms were a little brighter, but usually no changes were noted. In general, if there were any comments, they were favorable with respect to the reflectors.

Questions that the occupants were asked to answer in surveys after reflectors were installed into rooms in which they worked:

1. What's the weather like? Is it sunny, cloudy, dark, etc...
2. How do you feel about the lighting now? Is it too bright, not bright enough, just right?
3. Have you noticed any problems due to glare when working at your desk or computer?
4. Do you use task lighting when working? Do you feel that you need to have some if you don't have any at the moment?
5. Does the room seem any darker or brighter than before?
6. Do you notice differences in light levels when moving throughout the room?
7. Do you like the lighting? Do you dislike it? Does it just not matter?
8. How do the walls look? Are there any shadows that weren't there before? Are they lighter, darker or the same as before?
9. Do you notice any changes in the lighting in general?

Appendix E: Measurement Points for Average Room Illuminance Calculations

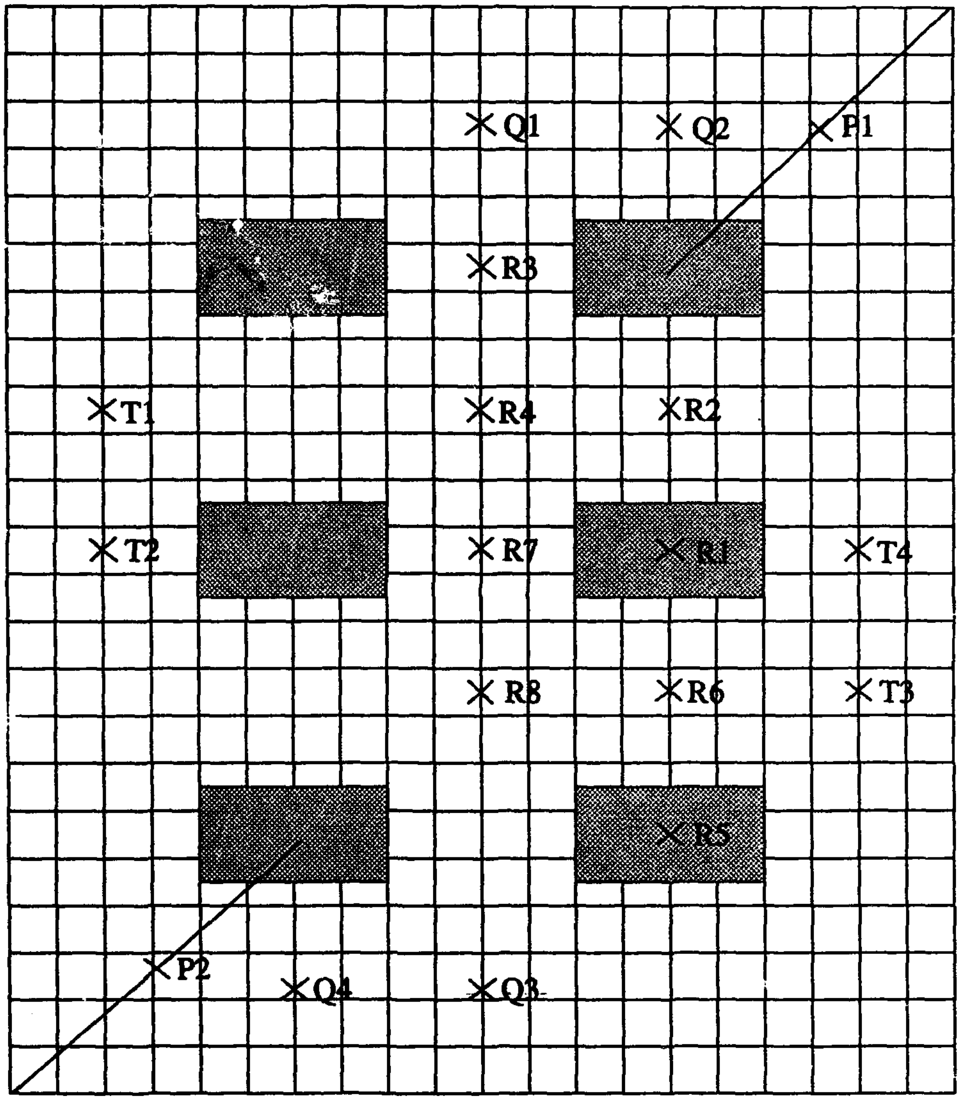

Figure E1. Measurement points for room A.

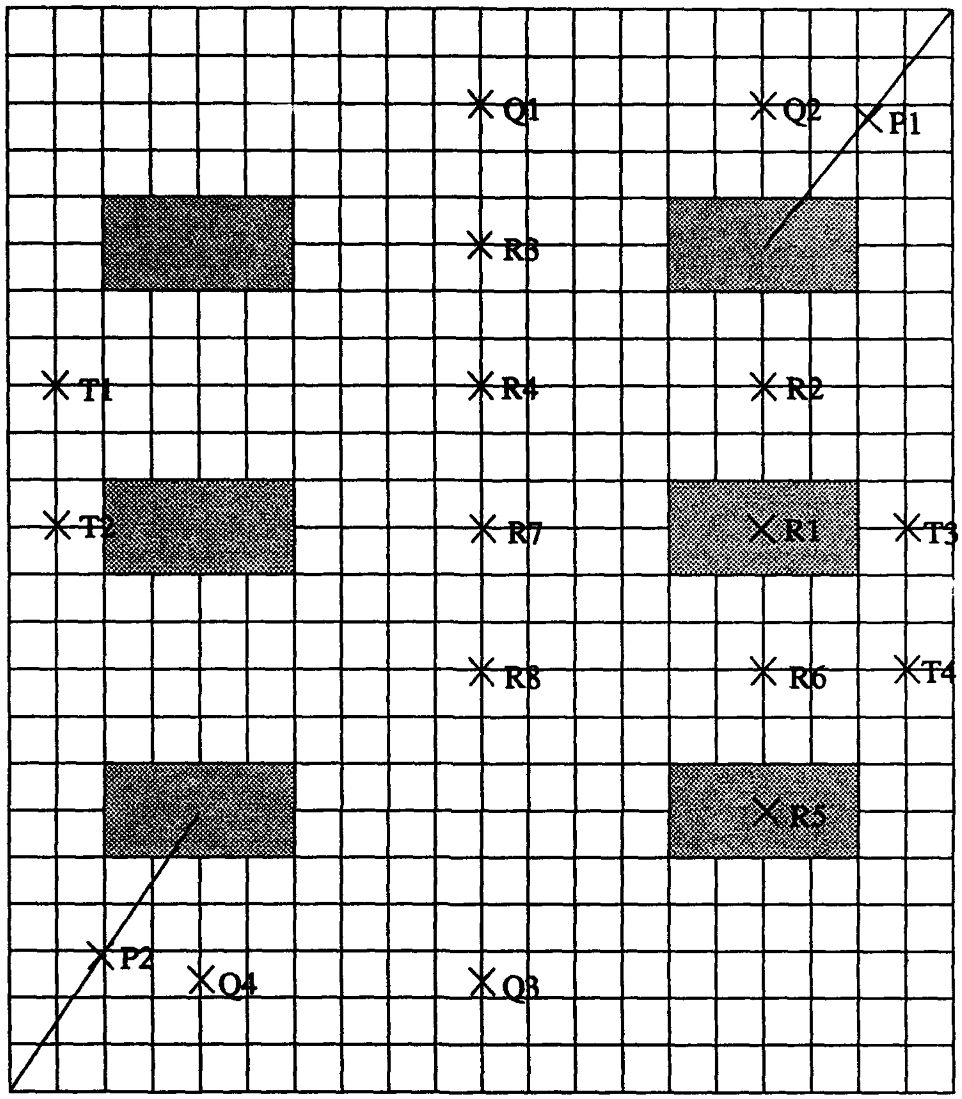

Figure E2. Measurement points for room B.

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