Title
Lighting Retrofit Study

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Publication Date
1990-09-01

LBL-31350
UC-350

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Plant Engineering Department

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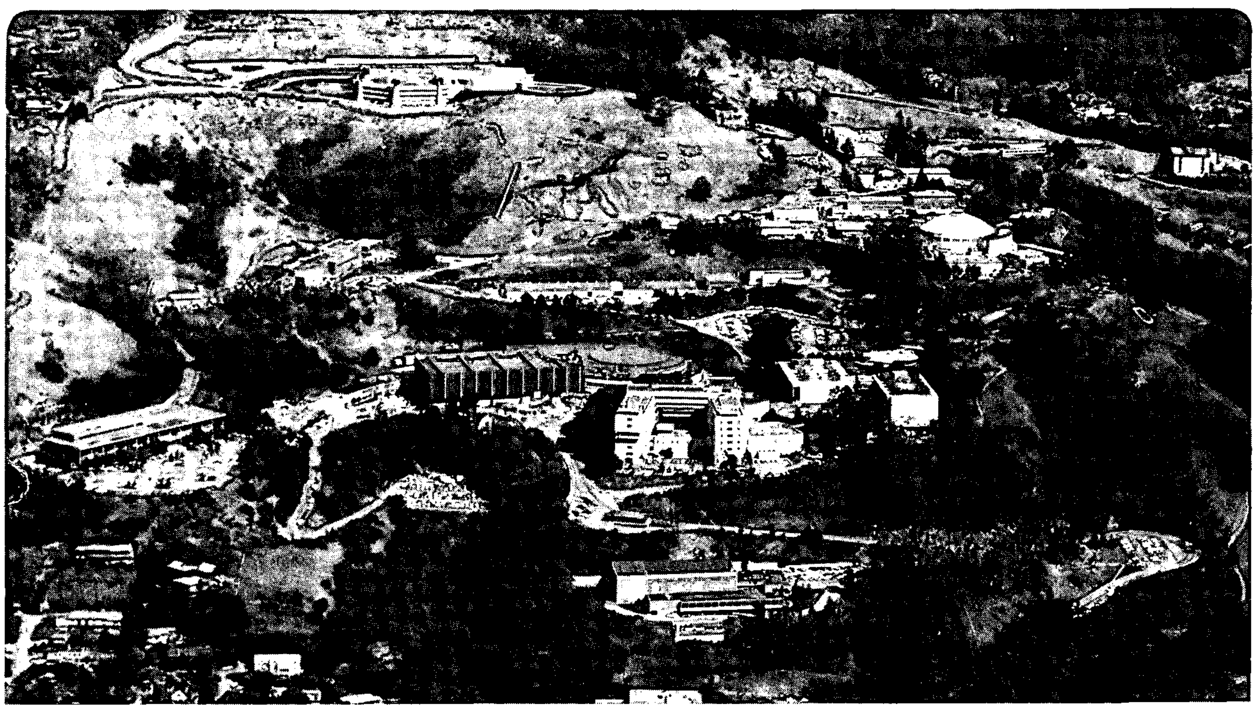
September 1991



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

Lighting Retrofit Study

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ABSTRACT

The Lighting Retrofit Study was an effort to determine the most cost- effective methods of retrofitting several configurations of lighting systems at Lawrence Berkeley Laboratory (LBL) and Lawrence Livermore National Laboratory (LLNL). We developed a test protocol to compare a variety of lighting technologies for their applicability in labs and offices and designed and constructed a novel lighting contrast potential meter to allow for comparison of lighting quality as well as quantity.

THE LIGHTING RETROFIT - INTRODUCTION AND SCOPE OF WORK

The Lawrence Berkeley Laboratory (LBL) and the Lawrence Livermore National Laboratory (LLNL) are currently in the process of retrofitting a major part of their existing lighting systems. The options available for retrofitting are numerous and the technologies are undergoing rapid change, with new equipment and techniques constantly entering the market. In attempting to sort through these options we were often confronted with conflicting claims as to the most effective retrofit packages to implement. There is a great deal of data on the performance of individual components; however, there has been little research comparing the newest technologies in a controlled, systematic manner. The Lighting Retrofit Study was developed to address this lack of information by comparing retrofit options under field conditions. This test was not designed to be an exhaustive comparison of every product of the market, but rather, a conditional, real world test of several of the most commonly utilized retrofit options.

The LBL and LLNL sites each consist of over a hundred buildings spanning 50 years of age. It follows that there are dozens and perhaps hundreds of fixture types to consider for retrofits. However, the predominant space usage at both facilities is office and laboratory, and the predominant lighting systems are 2'x4' 4-lamp fluorescent fixtures and eight-foot, 2- and 3-lamp fluorescent fixtures. Retrofit measures for these fixtures are the focus of this study.

We conducted the test in three separate areas. Each area represents a different type of space and lighting system found at the labs, namely 1) larger lighting layouts with 4 or more 2'x4' fluorescent fixtures laid out in a grid; 2) laboratories and shop areas with 8' fluorescent fixtures; and 3) small offices with 2 each 2'x4' fluorescent fixtures.

It is useful to divide retrofit measures into two types: those that increase the efficiency and effectiveness of the luminaire, making the most of the light that is produced by the lamps; and those that use new technologies to produce more light or higher quality light with less energy. An example of the first type of measure is the installation of specular reflectors, or changing the diffuser. The purpose of this type of retrofit is to maximize the output of light from the fixture and optimize its distribution. The second type of measure calls for the installation of lamps and ballasts which produce the most light for the power consumed. An example would be the new generation of ballasts that utilize solid state technology (high frequency electronic ballasts) and premium tri-phosphor lamps. This combination of ballasts and lamps has a potential efficacy of nearly 100 lumens/watt, produces light with a very high color rendition index, and creates no audible hum or visible flicker. Our study considered both kinds of retrofits.

PROCEDURE

Selecting the Test Areas

The Lighting Retrofit Study consists of illuminance and power measurements of a variety of lighting systems at three locations at LBL and LLNL.

Area 1 - 2 Foot by 4 Foot Fixtures - Conference Room

We selected a conference room at LBL (Building 70A, Room 3377) for the test of 2'x4' retrofit options. The room originally had 11 fixtures spaced 8 feet by 9 feet apart, at 10 feet above the floor (See Figure 1). One of the fixtures we removed to improve the symmetry and create an even number of fixtures for tandem wiring. The existing fixtures were 4-lamp, F48T12 (40 watt instant-start) with instant start core and coil ballasts that had been delamped to 2 lamps per fixture. The diffusers were acrylic lenses (K-12 type pattern).

Area 2 - 8 Foot Fluorescent Fixtures

We compared retrofit options for 8' fluorescent fixtures in an unused laboratory at LBL (Building 70A, Room 4405). We wired four fixtures at one end of the lab for testing and turned off the remaining fixtures (See Figure 2).

Area 3 - 2 Foot by 4 Foot Fixtures - Small Office

At LLNL, we selected five identical offices with 2 each 2'x4' 4-lamp fluorescent fixtures, to test selected measures side by side (See Figure 3).

In each room we laid out a grid of points at which to take the lighting readings. The grids we selected represent a compromise between taking an excessive number of measurements and covering the room well enough to discern differences in illuminance levels across, under, and between the fixtures. After installing each retrofit option, we turned on the lamps and allowed the fixtures to warm up and the power readings to stabilize. This typically took 20-30 minutes. Because the efficacy of any system is sensitive to temperature, the tests were all made at similar room temperatures. No effort was made to measure luminaire temperature as any internal variations would be a characteristic of the system being tested and not subject to adjustment.

Light and Power Measurement

The objective of the study was to compare a variety of retrofits on the basis of light quantity, light quality, power consumption, and characteristics effecting the cost of installation and maintenance.

For the purposes of this study we developed a measurement apparatus to assess the distribution of light at measurement points within the space. This system measures vertical and horizontal illuminance at 30 inches above the floor for four different viewing orientations (vertical and horizontal refer to the plane of the sensor, i.e. a sensor laid flat on a table measures horizontal illuminance). The vertical and horizontal illuminance measurements for each viewing orientation are combined in a analytical expression to develop an estimation of the contrast potential for both vertical and horizontal tasks. This measurement apparatus is made up of 5 illuminance detectors housed within a positioning system which is mounted on a movable desk. The detectors are connected to a lap top computer where data is processed and stored. The task plane with the measurement system is designed to be movable in order to facilitate measurements throughout the space with different positions and orientation with respect to the overhead lighting system.

The combination of vertical and horizontal illuminance measurements allows for the determination of the relative directionality of the incident flux at the task. A single horizontal measurement of illuminance simply measures the total flux incident on the task plane with no estimation of the directionality of the incident flux. Combined with a series of vertical illuminance measurements the relative directional contribution to the horizontal component can be estimated by comparing the horizontal with the vertical measurements. Combining a horizontal and vertical measurement allows for an estimate of the contrast or glare potential for any particular lighting arrangement. A simple expression has been developed which takes the horizontal illuminance and subtracts the vertical measurement for straight ahead viewing. This number is normalized to the horizontal, i.e., (H-V)/H = contrast potential. The contrast potential calculated in this manner has been found to be well correlated to the actual contrast (Siminovitch 1990).

The horizontal illuminance data was analyzed to provide information on footcandle levels beneath and between the fixtures, and the vertical illuminance data was analyzed to determine whether any retrofit option provides substantially improved quality of light.

We took voltage, current and power measurements with a Dranetz 808 recording power meter. We calibrated the meter against a Valhalla 2101 digital volt-ampere-wattmeter. To increase the resolution of the current measurements we constructed a five-turn coil. Line voltage was measured periodically and found to be consistent to within 2%.

Selecting the Retrofit Measures

After reviewing the literature and noting recent developments, we compiled a list of the most promising retrofit technologies. From this menu of retrofit options, we developed a test plan for each of the rooms. Each test compares a combination of ballasts, lamps, diffusers and, in some cases, reflectors (See Appendix B). Some of the measures called for removing a lamp from each fixture and wiring pairs of fixtures together on the same ballast. This procedure is referred to as "tandem wiring".

All of the materials were purchased through commercial distributors and are generally available to the public. In the cases where the brand of the material tested might have altered the test results, high quality products were specified so that each measure was tested under the best conditions. For example, the specular reflector used in the test was selected based on the response from competing manufacturers that it equalled the performance of the best products on the market. The standard (one size fits all) aluminum reflector was chosen as a least-cost item to determine what affect the quality of the material and its design have on the optical characteristics.

RESULTS

Complete results for all the tests are presented in Appendix C. A summarized form of each test follows.

Area 1 - 2 Foot by 4 Foot Fixtures - Conference Room

Establishing the Base Case

The existing lighting system consisted of 10 each 4-lamp 2'x4' fluorescent fixtures which had been delamped to 2 lamps per fixture operated by a core and coil ballast with a prismatic acrylic lens for light distribution.
This system provided 37 average footcandles, while consuming 95 watts per fixture (See Table 1).

Table 1. 2' x 4' Base Case

MEASURE	AVERAGE FC	WATTS	WATTS/FC	TEST #
OUTBOARD 2 LAMPS	37	95	2.60	1b
INBOARD 2 LAMPS	40	95	2.41	1a
2 LAMPS CLEANED	40	97	2.43	2
NEW LAMPS W/ OLD LENS	45	99	2.19	6
NEW LAMPS/NEW LENS "BASE CASE"	**48**	**97**	2.02	5
NEW LAMPS W/PARABOLIC LENS	41	99	2.38	8
NEW LAMPS W/BATWING LENS	47	99	2.11	7

By moving the two old lamps from the outboard to the inboard positions, we witnessed an 8% gain in average footcandles. Cleaning the lamps and fixture did nothing to the light levels, but installing new lamps added 14% more light. Installing new acrylic K-12 pattern lenses increased the average footcandles by 3 to 48, a 30% boost from the initial condition. The other diffuser options, parabolic cells and batwing lenses, show 15% and 2% reductions in light levels respectively, as compared to the new acrylic K-12 lens.

The base case, against which other measures will be compared, is the condition of 2 new T-12 (1-1/2 inch diameter) 40 watt, warm white lamps operated by a core and coil ballast, with a new acrylic K-12 diffuser. This represents the current system at its maximum possible output.

Single Lamp Options

Table 2 shows the comparison of the base case to the single lamp per fixture options. While the efficiency of the single lamp with high frequency electronic ballast systems is quite good, especially in conjunction with the reflector, none of these systems can maintain original light levels.

Therefore, while these options may be useful in areas which are currently overlit, and amenable to tandem wiring, none would suffice as a general retrofit measure. This is contrary to LBL's pre-test assumption that a combination of one half the baseline number of high output lamps and ballasts with a specular reflector would yield the baseline light levels.

Table 2. Base Case vs Single Lamp Options

MEASURE	AVERAGE FC	WATTS	WATTS/FC	TEST #
BASE CASE	**48**	**97**	2.02	5
AX	25	36	1.43	10
AX /SPEC3	30	36	1.20	9
AX/1.08	32	43	1.35	11
AX/1.08/SPEC3	38	43	1.14	12

AX - High Output T-10 Lamp
SPEC 3 - Specular Reflector 3 (See Appendix A)
1.08 - 1.08 BF HF Electronic Ballast

High-Frequency Electronic Ballast with T-8 Lamps

Table 3 compares the options using various combinations of T-8 (one inch diameter) lamps, high-frequency electronic ballasts, and reflectors. The performance of the two-lamp reflectors can be determined by comparing the results of the T-8 lamps and 0.6 BF (Ballast Factor) with and without the reflector. The % Gain column in Table 3 indicates the increase in average footcandles attributable to the reflector. The inexpensive aluminum reflector actually produced no light increase, while the silver specular reflector produced a 22% increase.

Table 3. Effect of Reflectors

MEASURE	AVERAGE FC	WATTS	WATTS/FC	% GAIN	TEST #
BASE CASE	48	97	2.02		5
T-8/0.6BF	31	43	1.38		19
T-8/0.6BF/ALUM	31	44	1.39	0	17
T-8/0.6BF/SPEC1	34	44	1.28	10	16
T-8/0.6BF/SPEC2	38	43	1.12	22	22
T-8/.98BF	51	60	1.19		18
T-8/.98BF/SPEC1	55	61	1.11	8	20

BF -Ballast Factor
ALUM - Aluminum Reflector
SPEC 1 - Specular Reflector 1 (See Appendix A
SPEC 2 - Specular Reflector 2 (See Appendix A)

Also of note in Table 3, is that the system using T-8 lamps and full output high frequency electronic ballasts is the only one to equal or exceed the baseline average footcandle levels.

Contrast Results: 2' x 4' Fixtures

Lighting contrast data was collected for every option, however,we focused on the results from the four measures that had different diffusers on the same fixture/lamp/ballast system.

Horizontal and vertical illuminance measurements were used to derive a number representing the contrast potential in each of the four cardinal directions at each measurement point. The contrast potential numbers for the four diffusers were ranked from best to worst, with higher contrast considered better. The diffuser giving the highest contrast was assigned a 4, the second best a 3, and so on for each of four measurement points in the grid. The four points 8, 9, 12, and 13, were selected to show the effect of work space placement and direction on lighting quality (See Figure 1). The rankings were combined and the average placing of each diffuser is presented in Table 4.

Clearly, the parabolic lens provides the best contrast conditions in most cases. This is to be expected due to the nearly complete attenuation of light emitted at high angles. The no-lens case provides the worst contrast potential, which is also to be expected. What is interesting is that the K-12 lens performs better than the batwing lens. Theory would suggest that the batwing reduces light output in the offending glare zones thereby providing better lighting quality.

Table 4 Contrast Rankings

(ALL POINTS)	AVERAGE RANK	PT 8	PT 9	PT 12	PT 13
PARABOLIC	3.19	3.5	3.8	3.0	2.5
K-12	3.06	3.0	2.8	2.5	4.0
BATWING	2.56	2.5	2.5	3.0	2.3
NO-LENS	1.19	1.0	1.0	1.5	1.3

The orientation and placement of the test stand had much more impact on contrast potential, and hence lighting quality, than the type of lens utilized.

See Appendix A for complete list of equipment tested.

Eight-Foot Fluorescent Fixture Test Results

Appendix C is a complete list of results for the eight-foot fixture tests.

The test of eight-foot fluorescent lighting systems started with the existing industrial-style fixtures with uplight (slotted reflectors), with 2 each F96T12 warm white lamps operated by a 2F96T12 energy saving core and coil ballast. The fixtures had straight blade, egg crate style diffusers. Each subsequent system was tested with and without the diffusers, and it was determined that removing the diffusers increased light output an average of 10%. For purposes of comparison, the remainder of the tests presented in Tables 5 and 6 were conducted with the egg crate diffusers removed.

The results are presented in two groups, those that involved tandem wiring and those that did not. The results are shown sorted by watts per average footcandle, with the options that provided at least 50 footcandles shown in bold.

Eight Foot Tests - Two Lamps per Fixture Options

The existing conditions for the eight foot fixtures produced an average 60 footcandles. Cleaning the fixtures and installing new lamps brought the average light level to 64 footcandles, a 7 % increase. This is the base case for the eight-foot fixtures.

Of the non-tandem wired options, the high frequency (HF) electronic ballast/energy saver (ES) lamp option had the best watts/footcandle ratio and provided light levels nearly equal to baseline levels.

The HF ballast in combination with either new warm white lamps or the D35 (3500 Degree color temperature) consumed roughly 25% less energy than the Energy Saver and produced 12% more light.

Table 5. Two-Lamp Measures

MEASURE	AVG FC	WATTS/FIXTURE	WATTS/FC	TEST #
HF BALLAST/ES LAMP	62	107	1.72	12
HF BALLAST/D35 LAMP	68	131	1.93	27
HF BALLAST /WW LAMP	70	138	1.97	3
C&C BALLAST/NEW WW LAMP	64	147	2.29	7
C&C BALLAST/ OLD WW LAMPS	60	144	2.41	2

Eight-Foot Delamped and Tandem Wired Option

Of the delamped and tandem wired options, both the aluminum and the specular silver reflector options performed very well (see Table 6). This is due in part to the fact that by installing a reflector in these fixtures, light which had been illuminating the ceiling was directed downward. While this may create impressive gains in efficiency, the darkened ceiling cavity may be objectionable to some. In the case of recessed 8' fixtures, one would expect the gains from reflectors to be not nearly so great.

Table 6. Measures Using Tandem Wiring

MEASURE BALLAST/LAMP/REF	AVG FC	WATTS/FIXTURE	WATTS/FC	TEST #
HO/ES/SPEC 1	63	81	1.28	22
HO/D35/SPEC 1	69	96	1.39	23
HO/ALUM 2	64	97	1.52	26
HF/WW/SPEC 1	45	69	1.53	17
HF/WW/ALUM 1	40	69	1.71	16
HO/D35/ALUM 1	55	96	1.73	25
HO/ES	46	81	1.76	18
HO/D35HO	51	96	1.86	24
HF/WW	35	68	1.95	13
C&C/(2) WW (BASE CASE)	64	147	2.29	

HO	- High Output (800ma)
ES	- Energy Saving Lamp (60 Watt)
SPEC 1	- Specular Reflector 1
ALUM 2	- Aluminum Reflector 2
C&C	- Core and Coil Ballast
WW	- Warm White color temperature
D35	- 3500° K color temperature

In the case of our test room the act of tandem wiring was simplified by the fact that the fixtures were mounted end to end along the room. As the determining factor in selecting the best retrofit option for any system is the cost of that measure, the degree of difficulty in tandem wiring the fixtures could become very important.

Note that the only delamped and tandem-wired options that produced at least 50 footcandles employed High Output ballasts. Reflectors boosted the output enough to allow for lower wattage, energy saving lamps.

One additional measure that shows promise is replacing eight foot fixtures with a four lamp T-8 fixture with HF electronic ballasts. A side-by-side comparison of the T-8 and the eight foot fixtures found the T-8 producing 7% more light and consuming 25% less energy.

Results - Livermore Offices

All five of the rooms tested at Livermore started with lighting levels above 100 footcandles. The offices had 2 each 4-lamp fluorescent fixtures. The layout is shown in Figure 3. Delamping was the obvious strategy. The results of delamping with various ballast lamp combinations are shown in Figure 4.

The T-8 retrofits were well received by the occupants, particularly because of the improved color rendering.

CONCLUSIONS

The purpose of this study was to evaluate common retrofit measures under field conditions. In addition to gathering information on the performance of the various retrofits, we investigated other factors affecting their installation and operation. We also encountered some unforeseen problems.

The lighting retrofit represents an opportunity to use new technologies and techniques to upgrade and redesign existing lighting systems with the goal of improving lighting conditions and cost-effectively reducing power consumed. Of the measures we tested, almost all could successfully meet this criteria in some situations. No one measure would be right for every situation. The initial condition of the lighting system and the design goals will dictate which of these measures is used. New lamps, ballasts, lenses and reflectors might each be called for depending on the circumstances.

We introduced the concept of two types of retrofit: modifications which affect the fixture efficiency, and changes in the light-producing system. For the majority of situations, those where the fixture is in reasonably good condition, the system efficiency measures are preferred.

For example, LBL facilities were delamped over 15 years ago when energy conservation first became a priority of management. Facility maintenance has continued to push for conservation throughout the site and there are very few grossly overlit areas. We learned from the tests that delamping from two lamps to one and adding a reflector would not meet the existing conditions and in most cases would not produce required lighting levels.

However, the retrofit to full output high frequency electronic ballasts with T-8 lamps matched or exceeded the existing footcandle levels and provided improved light quality. Savings similar to the single-lamp measure can be obtained if low output "tuned" ballasts are used in areas which require less light. A "tuned" T-8 lighting system can save more energy than delamping with reflectors while maintaining higher lighting levels. Further, this retrofit option provides reduced lumen depreciation and higher light quality (color rendition) with reduced hum and flicker.

An example of the other extreme was the Livermore case, where the rooms were initially greatly overlit. There, delamping and changing to a T-8 system provided substantial savings at low cost. No additional light was required after installing the T-8 lighting system. In fact, occupants responded favorably to the more comfortable light conditions.

For those situations where the existing fixture is operating poorly due to deterioration or poor design, the installation of reflectors may be considered. Obviously any improved output from the reflector will depend on the condition of the fixture before the retrofit. In addition, the design of the reflector must be such that the light from the lamps will pass through the diffuser after the fewest possible bounces. Indeed, the reflectance of the leading reflectors is similar, the major difference in the products being the process used to produce the sheets and their shape. Therefore, it was interesting to see that the performance of the reflectors we tested was so varied. Reflector performance varied from 0% to 22% gains for the 2-lamp 2'x4' fixtures and 30% for the eight-foot fixtures. The larger gains were accompanied by an increase in illuminance modulation across the room, meaning the reflector tended to direct more light straight down.

Obviously the highest system efficiency can be obtained by combining a T-8 lighting system with reflectors. The boost in light levels provided by the reflector could be captured by further tuning of the ballast (or a delamp in an over lit situation). However, based on reflector retrofit costs, energy costs, and operating hours at LBL this option is not cost effective.

Retrofits for Lighting Quality

Lighting quality will continue to be an issue in new and retrofit lighting systems. There is no question that improved quality can mean lower lighting levels and lower energy bills. The single most important factor affecting the lighting conditions at any task area is the placement of the task relative to the existing lighting system. Unfortunately the designer of a lighting retrofit is seldom free to change the layout of the lighting system or the work areas. Of the measures we tested which claim to improve light quality by redistributing the output of the fixture, only the parabolic louver significantly reduced glare and provided enhanced contrast potential. However, this enhancement comes at a cost of efficiency of approximately 15%. The standard acrylic K-12 diffuser performs well for general lighting conditions.

APPPENDIX A

LIGHTING RETROFIT STUDY EQUIPMENT LIST

<u>LAMPS</u>

Description	Initial Lumens	Watts
<u>4' Lamps</u>		
F48T12WW	2975	40
F32T8/35K	2900	32
F32TL80/35K	3050	32
F40AX/35K	3700	40
<u>8' Lamps</u>		
F96T12/WW	6400	75
F96T12/D35	6425	75
F96T12/D35/ES	5750	60
F96T12/D35/HO/ES	8350	95
F96T12/D35/HO	9200	110

<u>BALLASTS</u>

Description	Ballast Factor	Wattage
<u>Ballasts for 4' lamps</u>		
F40T12 Core and Coil (C&C)	.95	95
F40T12 HF Electronic	.83	73
F40T12 1.08 HF Electronic	1.08	86
F32T8 HF Electronic-Instant Start	.98	61
F32T8 0.6 HF Electronic-Rapid Start	.61	44

Ballasts for 8' lamps		
Core and Coil (C&C)	.84	145
T-12 HF Electronic	.95	130
T-12 HO/HF (w/Std HO lamp)	.98	190
T-12 HO/HF (w/HO/ES lamp)	.98	161

General notes

1) All lamp specifications come from Phillips, Sylvania or GE lamp catalogs
2) D35-3500K Color temperature
3) HF-High Frequency
4) HO-High Output (800 ma) lamp requires 800 ma ballast

REFLECTORS

Four Foot:

Alum	-	Aluminum
Spec 1	-	Dielectric-coated specular 2-lamp
Spec 2	-	Silver-coated specular 2-lamp
Spec 3	-	Dielectric-coated specular 1-lamp

Eight Foot:

Alum 1	-	Inexpensive aluminum
Alum 2	-	High quality polished aluminum
Spec 1	-	Dielectric-coated aluminum

DIFFUSERS

Four Foot:

Acrylic K-12	Clear Acrylic K-12
Batwing Lens	"Radial Batwing" Spectral Distribution Lens
Parabolic	3" Parabolic Louver-Aluminum w/semi-specular finish

Appendix B

EQUIPMENT LIST- 8 FOOT FIXTURE TEST

Test	Ballast	Lamps	Lenses	Reflectors
1	1 HF (1 fixt)	4 FO32T8	none	none
2	1 Core (1 fixt)	old 2 F96T12	none	none
3	1 Core (1 fixt)	old 2 F96T12	louver	none
4	1 Core (4 fixt)	old 2 F96T12	louver	none
5	1 Core	old 2 F96T12 (clean)	louver (clean)	none
6	1 Core	old 2 F96T12 (clean)	none	none
7	1 Core	2 F96T12/WW	none	none
8	1 Core	2 F96T12/WW	louver	none
9	1 HF	2 F96T12/WW	none	none
10	1 HF	2 F96T12/WW	louver	none
11	1 HF	2 F96T12/D35/ES	louver	none
12	1 HF	2 F96T12/D35/ES	none	none
13	1/2 HF	1 F96T12/WW	none	none
14	1/2 HF	1 F96T12/WW	louver	none
15	1/2 HF	1 F96T12/WW	louver	alum 1 lamp
16	1/2 HF	1 F96T12/WW	none	alum 1 lamp
17	1/2 HF	1 F96T12/WW	none	specular 1 lamp
18	1/2 HF	1 F96T12/WW	louver	specular 1 lamp
19	1/2 HF/HO	1 F96T12/D35/HO/ES	none	none
20	1/2 HF/HO	1 F96T12/D35/HO/ES	louver	none
21	1/2 HF/HO	1 F96T12/D35/HO/ES	louver	specular 1 lamp
22	1/2 HF/HO	1 F96T12/D35/HO/ES	none	specular 1 lamp
23	1/2 HF/HO	1 F96T12/D35/HO	none	specular 1 lamp
24	1/2 HF/HO	1 F96T12/D35/HO	none	none
25	1/2 HF/HO	1 F96T12/D35/HO	none	alum 1 lamp
26	1/2 HF/HO	1 F96T12/D35/HO	none	alum 1 lamp
27	HF	2 F96T12/D35	none	none

Appendix C

APPENDIX C PART 1

TEST	BALLAST(1)					LENSES (2)				LAMPS (3)						REFLECTORS(4)				RESULTS						
	T-12	T-8	T-8	T-12	T-12	OLD	NEW	BAT-	PARA-	OLD	CLEAN	NEW	FO32	FO32	F40AX	ALUM	SPEC	SPEC	SPEC	FOOTCANDLES			STD	WATTS		
	CORE	HF	0.6 HF	HF	1.08 HF	K-12	K-12	WING	BOLIC	T12	T12	T12	T8	TL80	T-10		1	2	3	AVG	MIN	MAX	DEV	WATTS	SAVED	COMMENTS/REMARKS
1a	1					X				2										39.60	35.70	43.10	2.19	954	*	INBOARD 2 LAMPS
1b	1					X				2										36.60	33.20	39.70	2.00	950	*	OUTBOARD 2 LAMPS
2	1					X					2									39.73	36.70	43.60	1.95	966	*	CLEAN LAMPS
3	2					X						4								85.09	74.40	93.20	4.63	1831	*	4 LAMP OLD K-12
4	2						X					4								86.69	75.40	96.70	5.27	1831	*	4 LAMP NEW K-12
5	1						X					2								**47.82**	**41.60**	**53.50**	**3.09**	**968**	*	**BASE CASE**
6	1					X						2								45.42	40.20	51.60	2.99	994	-26	B. C. W/OLD K-12
7	1							X				2								46.69	38.70	56.00	5.68	987	-19	B. C. W/BATWING
8	1								X			2								41.36	34.70	48.10	4.15	986	-18	B.C. W/PARABOLIC
9				0.50			X								1				X	30.39	28.30	34.70	1.56	364	604	AX W/SPEC3
10				0.50			X								1					25.44	23.80	28.80	1.27	364	604	AX
11					0.50		X								1					31.54	29.70	35.70	1.57	427	541	AX 1.08
12					0.50		X								1				X	37.52	35.20	42.10	1.76	426	542	AX 1.08 W/SPEC3
13		1					X						2							**50.76**	**46.10**	**56.50**	**2.73**	**603**	**365**	**T-8 K12**
14		1						X					2							**52.10**	**44.60**	**58.50**	**4.38**	**600**	**368**	**T-8 BATWING**
15		1							X				2							42.91	36.2	50.6	4.77	611	357	T-8 PARABOLIC
16			1				X						2				X			34.04	31.70	38.70	1.59	435	533	T-8/0.7BF/SPEC1
17			1				X						2			X				31.18	27.80	34.70	2.28	435	533	T-8/0.7BF/ALUM
18		1											2							**54.31**	**49.10**	**60.00**	**2.64**	**608**	**360**	**T-8 NO-LENS**
19			1				X						2							31.43	28.30	34.70	1.70	433	535	T-8/0.7 BF
20		1					X						2				X			**55.03**	**50.60**	**62.00**	**2.65**	**611**	**357**	**T-8/SPEC1**
21			1				X							2						32.02	29.20	35.20	1.61	435	533	TL80/O.7 BF
22			1				X							2				X		38.37	34.70	44.60	2.77	430	538	TL80/0.7BF/SPEC2

FOOTNOTES 1) BALLAST TYPES: T12 CORE .95 BF; T8 HF .98 BF; T8 0.6 HF .61 BF; T12 HF .83 BF; T12 1.08 HF 1.08 BF.

.0.

3) LAMPS: ALL T12'S ARE WARM WHITE;T8 AND T10'S ARE 3500K;TL80 IS PHILLIPS HIGH PERFORMANCE T8.

4) REFLECTORS: ALUM(2 LAMP INEXPENSIVE): SPEC1(DI-ELECTRIC COATED SPECULAR 2 LAMP): SPEC2(SILVER COATED SPECULAR 2 LAMP): SPEC3(DI-ELECTRIC COATED SPECULAR 1 LAMP

NOTES: 1) FOOTCANDLE READINGS ARE FOR A 25 POINT MEASUREMENT GRID

2) RESULTS: WATTS SAVED= WATTS FOR BASE CASE - WATTS FOR CURRENT OPTION

3) OPTIONS IN BOLD MEET MINIMUM FOOTCANDLE REQUIREMENTS

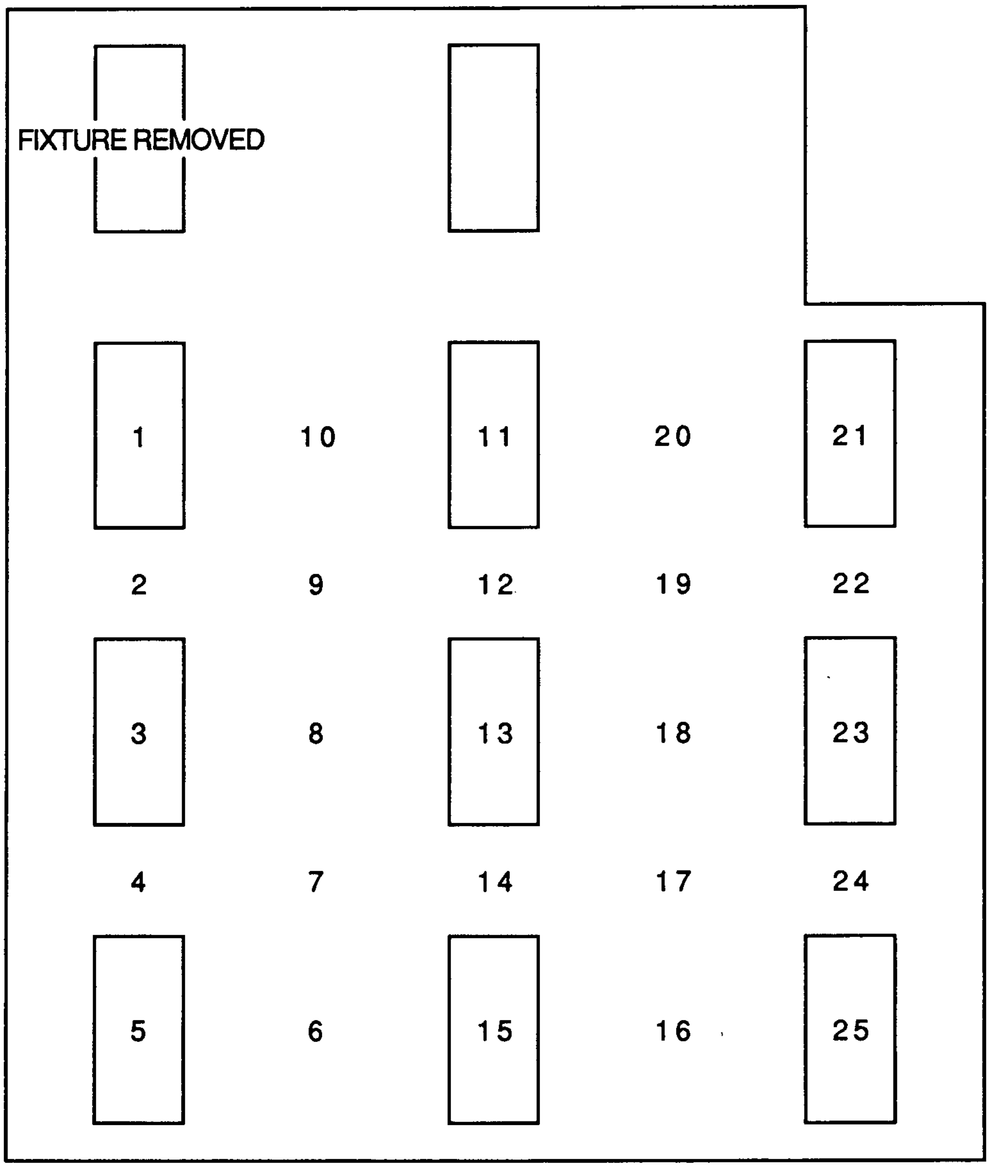
APPENDIX C PART 2

TESTS	BALLASTS(1)				LAMPS (2) F96T12							LOUVER		REFLECTOR		RESULTS						
	CORE COIL	HF	HO/HF	T-8	WW OLD	WW CLEAN	WW NEW	D35	D35 ES	D35 HO/ES	D35 HO	W	W/O	ALUM (3)	SPEC. (4)	AVERAGE	FOOTCANDLES MAX	MIN	STDEV	WATTS	WATTS/ SAVED	COMMENTS/REMARKS
1		1		4												29.93	*	*	*	110		ONE FIXTURE ONLY
2	1				2								X			26.77	*	*	*	137		ONE FIXTURE ONLY
3	1				2							X				26.60	*	*	*	137		ONE FIXTURE ONLY
4	1				2							X				53.24	67.90	35.70	11.27	582.00	6	DIRTY W/LOUVER
5	1					2						X				54.24	69.40	36.70	11.49	581.00	7	CLEAN W/LOUVER
6	1					2							X			59.71	74.90	42.10	10.87	576.00	12	CLEAN W/O LOUVER
7	1						2						X			64.21	80.30	45.60	11.47	588.00	0	**BASE CASE W/O LOUVER**
8	1						2					X				58.14	74.40	39.70	12.23	587.00	1	**BASE CASE W/LOUVER**
9		1					2						X			69.70	87.20	52.10	12.22	550.00	38	**HF**
10		1					2					X				63.23	80.80	46.10	12.85	550.00	38	**HF**
11		1							2			X				56.50	71.90	41.10	11.57	428.00	160	**HF BALLAST/SS LAMP**
12		1							2				X			62.23	78.30	46.60	11.06	428.00	160	**HF BALLAST/SS LAMP**
13		1/2X					1						X			34.61	43.10	25.30	6.19	270.20	318	TANDEM
14		1/2X					1					X				31.31	39.20	22.30	6.46	270.00	318	TANDEM
15		1/2X					1					X		X		34.15	42.60	24.30	7.35	276.00	312	TNDM W/REFLECTOR
16		1/2X					1						X	X		40.31	51.60	29.20	7.64	276.00	312	TNDM W/REFLECTOR
17		1/2X					1						X		X	45.31	59.00	33.20	8.78	277.00	311	TNDM W/REFLECTOR
18		1/2X					1					X			X	41.27	52.50	28.30	9.21	276.00	312	TNDM W/REFLECTOR
19			1/2X							1			X			46.14	58.00	33.70	8.31	324.00	264	TANDEM HO/SS
20			1/2X							1		X				42.43	54.50	29.20	9.08	324.00	264	TANDEM HO/SS
21			1/2X							1		X			X	59.05	79.30	36.70	14.16	324.00	264	**TNDM HO/SS W/RFLCTR**
22			1/2X							1			X		X	63.46	83.3	42.1	12.97	324.00	264	**TNDM HO/SS W/RFLCTR**
23			1/2X								1		X		X	68.5	90.2	45.1	14.3	382.00	206	**TANDEM HO W/RFLCTR**
24			1/2X								1		X			51.25	64.40	36.70	9.35	382.00	206	TANDEM HO
25			1/2X								1		X	X		55.26	72.90	39.20	10.82	383.00	205	**TNDM HO W/ALUM RFLCTR**
26			1/2X								1		X	X(5)		63.86	82.80	43.60	12.92	387.00	201	**TNDM HO W/HQ ALUM REF**
27		1						2					X			67.69	85.30	49.60	12.43	523.00	65	**HF/D35**

FOOTNOTES:
1) AN "X" IN THIS COLUMN INDICATES ONE BALLAST PER FIXTURE. "1/2X" INDICATES A TANDEM WIRED BALLAST FOR TWO FIXTURES
2) INEXPENSIVE ALUMINUM REFLECTOR
3) SPECULAR REFLECTOR (DI-ELECTRIC COATED ALUMINUM)
4) HIGH QUALITY ALUMINUM REFLECTOR

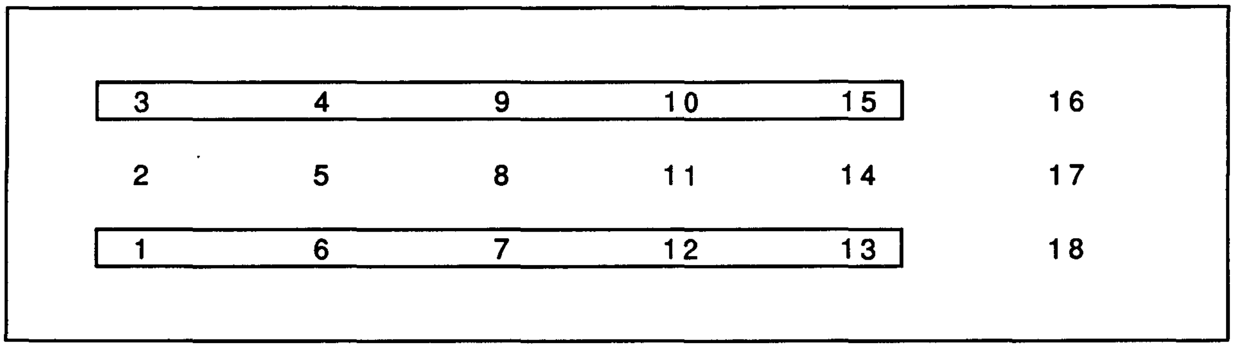
NOTES:
HF= HIGH FREQUENCY; AKA SOLID STATE/ELECTRONIC
HO/HF= HIGH OUTPUT/HIGH FREQUENCY (800ma LAMP CURRENT)
D35= 3500K COLOR TEMPERATURE
SS= SUPER SAVER (60 WATTS FOR STD; 95 WATTS FOR HO)
WW= WARM WHITE COLOR
OPTIONS IN BOLD MEET MINIMUM FOOTCANDLE REQUIREMENTS

FIGURE 1 B70A-3377 MEASUREMENT GRID



1-25 MEASUREMENT POINTS IN SEQUENCE
(Fixture spacing 8' x 9')

FIGURE 2 B70A-4405 MEASUREMENT GRID



POINTS 1-18 MEASUREMENT POINTS IN SEQUENCE
Fixtures mounted end to end-six feet between rows

Figure 3 Typical Office LLNL

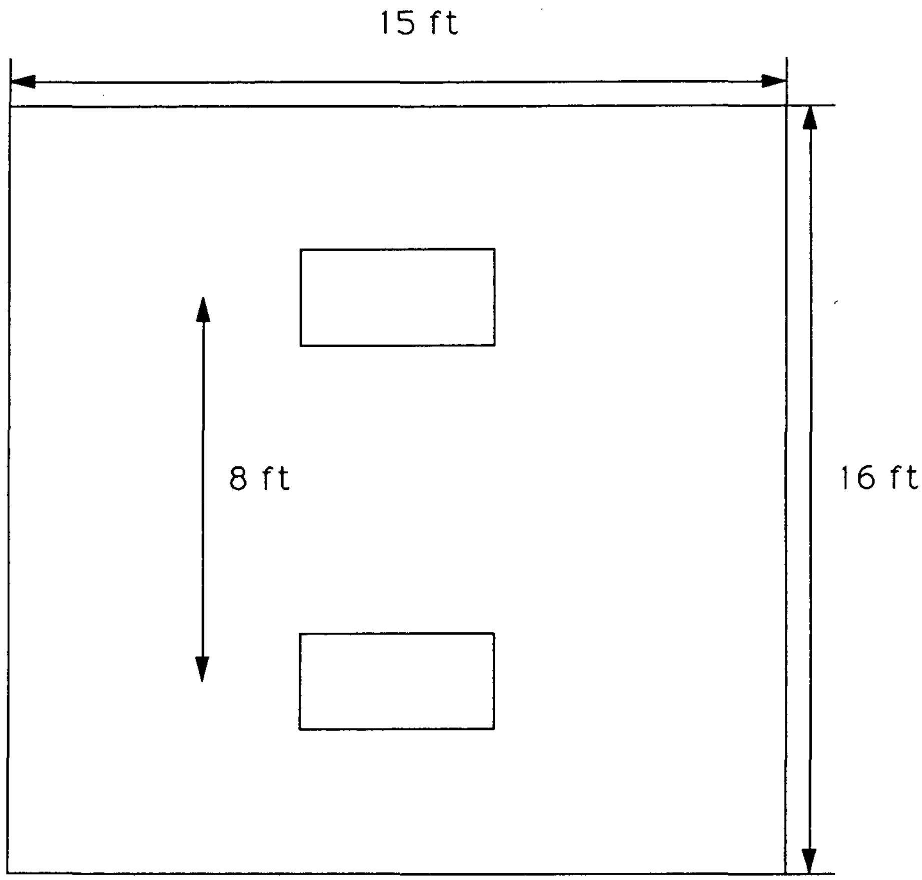


FIGURE 4 LLNL OFFICES BEFORE AND AFTER RETROFITTING

ROOM 1249	1251	1253	1255	1257
122 fc	118 fc	117 fc	117 fc	114 fc
121 fc	118 fc	117 fc	114 fc	115 fc
324 watts	312 watts	324 watts	314 watts	306 watts

BEFORE

(ALL T-12 ON CORE AND COIL BALLAST 4 LAMPS/FIXTURE)

70 fc	62 fc	53 fc	50 fc	54 fc
68 fc	60 fc	53 fc	50 fc	53 fc
121 watts	121 watts	162 watts	156 watts	155 watts

AFTER DELAMPING

(2LAMP T-8)	(2LAMP T-8)	(2LAMP T-12)	(2LAMP T-12)	(2LAMP T-12)

82 fc	62 fc	62 fc	65 fc	54 fc
82 fc	60 fc	62 fc	65 fc	53 fc
121 watts	121 watts	160 watts	158 watts	157 watts

AFTER ADDING REFLECTOR

(REFLECTOR 1)	(NONE)	(REFLECTOR 2)	(REFLECTOR 3)	(NONE)

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