PRE-RETROFIT LIGHTING STUDY AT THE UNIVERSITY OF TEXAS AT ARLINGTON

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ABSTRACT

In the summer of 1993 the University of Texas at Arlington Physical Plant Department submitted a request to the Energy Systems Lab to conduct a lighting study to determine the most cost-effective method of implementing energy-saving lighting retrofits in U.T. Arlington classrooms without compromising the Illuminating Engineering Society (IES) recommended minimum lighting levels.

A preliminary series of field tests was undertaken to get a sampling of classroom lighting levels on the U.T. Arlington campus and to determine whether lamp locations within the fixture would impact the amount of light output. This was followed by a series of lab tests conducted at the Energy Systems Lab, located on the Texas A&M University campus, to compare the light output of fixtures with different combinations of lamp types and locations within the fixture.

In order to evaluate the impact of the proposed lighting retrofit, a study was made to determine the capital investment required as weighed against energy cost savings. The results of the study are presented in the paper and a summary table is provided to take into account lamp and ballast performance compared with capital expenditure with respect to meeting IES minimum footcandle levels.

Based on the report findings it was recommended that a full, comprehensive survey be undertaken at UTA, to ensure that minimum lighting levels will be maintained, while also ensuring that the capital investment is the most cost-effective.

I. INTRODUCTION

During the course of a survey of potential operations and maintenance (O&M) savings at the University of Texas at Arlington, the UTA Physical Plant Department submitted a request to the Energy Systems Lab to conduct a lighting study. The purpose of the study is to determine the most cost-effective method of implementing energy-saving lighting retrofits in classrooms at U.T. Arlington without compromising the Illuminating Engineering Society (IES) recommended minimum lighting levels. UTA requested the comparison of various combinations of lamp quantities, lumen output, and lamp spacings to determine the most efficient footcandle levels from 2ft x 4ft, four-lamp fixtures, herein described as the Base Case, that have had two lamps removed.

Table 1
Fixture Type and Retrofit Description

Fixture Type	Fixture Description	Retrofit Description
A	4 lamp, 2x4	Remove 2 lamps, add reflector and 1 electronic ballast
B	2 lamp, 2x4	Add 1 electronic ballast
C	4 lamp, 1x4	Remove 2 lamps, add reflector and 1 electronic ballast
F	3 lamp, 2x4	Remove 1 lamp, add reflector and 1 electronic ballast
G	1 lamp, 1x4	Add 1 electronic ballast
H	3 lamp, 1x4	Remove 1 lamp, add reflector and 1 electronic ballast

The original Audit Report for the site recommended a lighting retrofit that included delamping, relamping with high efficiency lamps, the installation of high efficiency electronic ballasts, and the installation of specular reflectors. If the retrofit could be implemented **without** the use of specular reflectors, then a considerable amount of investment capital would be saved.

As a part of the Energy Cost Reduction Measure (ECRM) retrofit program, funded by LoanSTAR, the U.T. Arlington site has been granted a $2 million loan to implement a lighting retrofit in 20 buildings on the campus. The proposed ECRM includes: the installation of lighting reflectors and the delamping and installation of electronic ballasts in existing luminaires. Specifically, the ECRM requires that 28,085 new electronic ballasts be installed in place of standard ballasts, and 30,584

fluorescent reflectors be installed in existing fixtures. Table 1 presents the fixture types and the retrofit description for each.

Table 2
Summary of Illumination Level Fixture Tests Done by Solar Kinetics Inc.

Test	Fixture Condition	No. of Lamps & Type	Ballast Type	Illumination Level (% of Existing)
Base	Clean	4 - F40T12CW	Magnetic	—
Case 2	Not Clean	4 - F40T12CW	Magnetic	100
Case 3	***Reflector***	***2 - F40T12CW***	***Magnetic***	***78***
Case 4a	Reflector	2 - F40T12CW	Electronic	70
Case 4b	Reflector	2 - F40T12 34W	Electronic	62
Case 4c	Reflector	2 - F32T8 32W	Electronic	79

The audit-recommended lighting ECRM was based on an evaluation of the effects of fluorescent fixture delamping, reflector installation and lamp retrofitting. Test data were provided to the audit engineering firm by Solar Kinetics Inc. of Dallas, Texas. A series of six different case tests had been performed by Solar Kinetics Inc:

- Case 1: A Base Case test was established using a 2ft x 4ft, lay-in fluorescent fixture with standard magnetic ballasts and four F40T12CW lamps (3150 lumens each). The fixture had been cleaned prior to the test. Using a summation of footcandle readings taken at various test points, a "total" light output of 283.22 footcandles was measured.*
- Case 2: The Base Case (Case 1) was then repeated as Case 2 except that the fixture had **not** been cleaned. This test produced a light output of 86.8% of the Base Case. It was stated that since this test more closely represents the actual condition of fixtures in the field, any retrofit comparisons would be made relative to this condition.
- Case 3: The Case 3 test was based on using two F40T12CW lamps with a standard magnetic ballast and an aluminum specular reflector. The results indicated a lighting level of 78% of existing conditions (Case 2). *The Case 3 results were used as the basis of the ECRM savings calculations.*

Table 3
Summary of Audit Lighting Survey

Building	Classroom No.	IES Minimum fc	Existing fc	*New fc (78% of Existing)*
Activities	303	50	89	**69**
Geoscience	109	50	67	**52**
Engineering Lab	235	50	67	**52**
Hammond	129	50	99	**77**
Trimble	101	50	107	**83**
Business	150	50	83	**65**
Fine Arts	122	50	74	**58**
Life Science	120	50	120	**94**
University Hall	213	50	98	**76**
Science	125	50	91	**71**
Engineering I	212	50	91	**71**
Architecture	209	50	74	**58**
Engineering II	108	50	117	**91**

* Author's Note: Although a summation of footcandle readings taken at various test points was provided by Solar Kinetics Inc., the author feels that a presentation of lumen output or candlepower curves would have been more appropriate.

- Case 4a-c: The Case 4 study was a series of three tests with both electronic ballasts and specular reflectors but with three different lamp combinations. Case 4a used two F40T12 40W lamps which produced results of 70% of the existing lighting level (Case 2). Case 4b used two F40T12 34W lamps which produced results of 62% of the existing lighting level (Case 2). Case 4c used two F32T8 32W lamps which produced results of 79% of the existing level (Case 2). Table 2 summarizes the results of the Solar Kinetics Inc. fixture tests.

In addition to the lighting fixture tests shown in the above table, the audit report included a survey of representative lighting levels in 20 buildings on campus. The survey compared IES minimum foot-candle levels with existing minimum foot-candle levels and projected new (after retrofit) foot-candle levels. A summary of the audit survey is presented in Table 3. Table 3 includes only buildings with classrooms since they represent the majority of the retrofit, whereas the original audit summary included offices, restrooms, laboratories, and corridors. The column heading ***"New footcandles"*** represents the "78% of Existing" value displayed in Table 2 corresponding to the the Case 3 Test performed by Solar Kinetics Inc.

Table 3 displays existing footcandle levels for "representative" classrooms in each of 13 buildings. It can be seen that the existing footcandle levels range from a low of 67 footcandles to a high of 120 footcandles. The New footcandle levels were derived from multiplying the existing footcandle levels by 0.78. The New footcandle levels are presented for comparison with the current IES Minimum footcandle level of 50 footcandles. It can be seen that they range from a low of 52 footcandles to a high of 94 footcandles, all of which are above the 50 footcandle minimum.

II. CURRENT IES MINIMUM FC LEVELS

In order to confirm that the IES minimum footcandle levels were still current, we contacted IES National Headquarters in New York City. A spokesperson in the IESNA Technical Services Department quoted from the Lighting Handbook, 8th Edition, IESNA, 1993 that the recommended footcandle levels in classrooms were **50-75-100 footcandles**. It was suggested that the Chairman of the Schools and Classrooms Committee be contacted for additional information.

Mr. Shail Mahantic, Chairman of the School and College Lighting Committee, indicated that a current publication, entitled RP3, "Guide for Educational Facilities Lighting", is undergoing revision this year. One important change involves the idea that, as students get older, the classroom illumination levels should correspondingly increase. Current thinking suggests **50-55 footcandles** for elementary schools, **55-60 footcandles** for high schools, and **60-65 footcandles** for colleges. This will be recommended in their revised publication.

Table 4
Lamp Comparison Table (Based on 2 lamp systems)

	Lamp Types				
	Tri-phosphor			Halophosphor	
Ballast Types	**• 40W,T-12**	**• 42W,T-10**	**• 32W,T-8**	**• 40W,T12**	**• 34W,T12**
Standard ••	6204 lm	6768 lm	No	5734 lm	4664 lm
Magnetic	94W	97W	Systems	94W	84W
	66 lm/W	70 lm/W		61 lm/W	56 lm/W
Premium	6204 lm	6768 lm	5452 lm	5734 lm	4664 lm
Magnetic	88W	90W	72W	88W	72W
	71 lm/W	75 lm/W	76 lm/W	65 lm/W	65 lm/W
Electronic	5940 lm	6480 lm	5626 lm •••	5940 lm	4558 lm
	72W	76W	62W	72W	60W
	82 lm/W	85 lm/W	91 lm/W	76 lm/W	76 lm/W

III. LAMP/BALLAST COMPARISONS

Due to the increase in both the number and types of lamps and ballasts in the lighting industry, a literature review was conducted by the ESL to determine which ballast/lamp combinations were most efficient in terms of energy efficiency.

The most relevant report is a 1991 Electric Power Research Institute (EPRI) publication entitled "Retrofit Lighting Technologies". Table 4 presents a summary of data provided in the EPRI report.

Notes: • All lamps at 4100K color temperature
•• No longer manufactured
••• Using T-8 instant-start mode ballast with 0.97 ballast factor. For rapid-start T8 electronic ballast with 0.90 ballast factor, values are 5220 lm,61W, and 86 lm/W.

Author's Note: Lumen(lm) = the unit of luminous flux, or the time rate flow of light (luminous energy).

Two separate but related Federal laws have been enacted which have an effect on the lighting designer's choice of lamps and ballasts. Public Law 100-357, the "National Appliance Energy Conservation Ammendments of 1988," has established national standards for energy efficiency. For fluorescent lighting, the Ballast Efficacy Factor (BEF), which is determined by dividing relative light output by power input, determines compliance. The law covers only a few ballast types. However, these represent about 85% of all ballasts in use. The regulated ballast types must meet B.E.F. requirements and have a power factor of over 90%. The ballasts described as "Standard Magnetic" in Table 4 do not meet the B.E.F. requirements and are no longer manufactured

Additionally, in October 1992, legislation was passed mandating minimum efficacy and color rendering standards in the manufacturing of popular fluorescent and incandescent reflector lamp types commonly used in industrial and commercial applications. This legislation, called The National Energy Policy Act of 1992, affects general service F40 four-foot medium bi-pin, two-foot U-bent, F96T12 and F96T12/HO eight-foot fluorescent lamp types. As of October 31, 1995, the halophosphor 40W T12 lamp indicated in Table 4 will no longer be manufactured. The 34W T12 lamp currently meets minimum standards, but if the law becomes more stringent, it would no longer qualify.

Most pre-retrofit lighting installations currently have one of two recessed fixture types. The first consists of 2ft x 4ft, four-lamp F40T12 40W fixtures with a total lumen output of 11,468 lumens and a corresponding power input of 188W. The second consists of 2ft x 4ft, four-lamp F34T12 34W fixtures with a total output of 9328 lumens and a corresponding input of 168W.

Since the purpose of the lighting retrofit is to reduce energy consumption without compromising minimum IES lighting levels, the lighting engineer has a number of choices as indicated previously in Table 4. Using the 2x4, 4 lamp F40T12 40W as the Base Case, the use of two F32T8 lamps with electronic ballast would produce 5626 lumens with a power input of 62W. This represents a 51% reduction in lumen output with a corresponding 67% reduction in power input. If higher illumination levels are desired, then the use of two F42T10 lamps with electronic ballast would produce 6,480 lumens with a power input of 76W. This would result in a 44% reduction in lumen output and a 60% reduction in power input when compared with the Base Case. If any of the two lamp combinations do not produce the required lighting levels, the designer can use four F32T8 lamps with electronic ballast. This will produce 11,252 lumens with a power input of 124W. When compared with the base case, the lumen output will decrease by 2% with a 34% reduction in power input. Table 5 summarizes the results of the various lamp/ballast combinations.

Table 5
Comparison of Lamp/Ballast Combinations

Lamp Type	No. of Lamps	Ballast Type	Lumen Output	Lumen Reduction (% of Base)	Input Watts	Watt Reduction (% of Base)	Efficacy (lumens/W)
F40T12	4	Magnetic	11,468	Base	188	Base	61
F34T12	4	Magnetic	9,328	19	168	11	56
F32T8	4	Electronic	11,252	2	124	34	91
F32T8	2	Electronic	5,626	51	62	67	91
F42T10	2	Electronic	6,480	44	76	60	85
F42T10	2	Magnetic	6,768	41	90	52	75

It should be noted from Table 5 that of all the possible two lamp combinations, the two F42T10 lamps with magnetic ballast produce the maximum lumens, 6768 lumens, with an input power reduction of 52% when compared with the Base Case.

IV. T.U. ELECTRIC INCENTIVE

The local electric utility company, T.U. Electric, has an incentive program for lighting retrofits. On the basis of demand reduction, T.U. Electric will pay $100.00/kW for each kW saved. The incentive will be paid for either a reflector retrofit or a delamping/relamping that includes either T8 or T10 lamps with electronic ballast. It will also be paid on the basis of both a reflector and relamping retrofit. In order to qualify, the installation must be permanent. Based on the estimated demand savings of 2,781 kW/month reported in the audit, the incentive payment would be $278,100.

V. FIELD TESTS

At the request of the UTA Physical Plant personnel, a series of field measurements and tests were conducted on campus during the week of August 23, 1993. The purpose of the measurements and tests was to determine if a lighting retrofit based on delamping, relamping, lamp repositioning, and electronic ballasts would meet both the criteria of the T.U. Electric Incentive Program and the minimum IES foot-candle levels. If the use of reflectors could be avoided, it was estimated that half of the loan amount, or approximately $1 million would be saved. Since the aforementioned audit report had already sampled lighting levels in a "representative" classroom in each of 13 buildings, an additional 9 classrooms in three different buildings were chosen at random to obtain additional footcandle measurements. Typically, six to nine readings were taken in each room, then the mathematical average was calculated. The instrument used for measuring was a combination footcandle/footlambert meter manufactured by the AEMC Corp. of Boston, Mass. It consists of a model # CL2010F Lightmeter Module and a model # 2000 Multidisplay. The instrument was last calibrated in July, 1992 and has an accuracy of 0.7% of the reading ±3 counts on the 0-200 Fc scale. Results of the classroom measurements are listed in Table 6.

The new footcandle readings in Table 6 provide an interesting comparison with those in Table 3. On the basis of the New footcandle (78% of existing) criteria established in the audit report, only 1 of the 9 classrooms would be above the IES minimum, whereas all 13 of the classrooms surveyed in the audit report met the new footcandle criteria. We recommended that a much larger sampling of lighting levels be undertaken since it is critical that IES minimum levels not be compromised as a result of the retrofit.

In addition to the classroom measurements, two tests were conducted to compare the lighting levels of fixtures with four lamps on, two inboard lamps on, two outboard lamps on, and two lamps on but centered in their respective halves of the fixture on either side of the center-mounted ballast channel. The purpose was to determine if, by a simple process of removing two lamps, then relocating the remaining two, minimum IES footcandle levels could be maintained. Room 106 in the University Hall Building was selected at random. The room is 26 ft x 30 ft with light colored walls, ceiling and floor. The ceiling height is 9 ft. The room contains fourteen, 2 ft x 4 ft, four-lamp lay-in fixtures with center-mounted ballast channels. Due to the quantity of fixtures, it was decided that the time required to modify them to centered-lamp positions would be prohibitive. Consequently, three tests were performed, one each with four lamps on, two inboard lamps on, and two outboard lamps on. For each test, 12 footcandle readings were taken at the same locations, then mathematically averaged.

Since the lamp repositioning tests were not done in Room 106 of the University Hall Building, a smaller space was chosen with fewer fixtures. The chosen space

Table 6
Summary of UTA Classroom Lighting Level Measurements

Building	Location	Fixture Size	Lamp No & Type	Lamps On	Existing fc	New fc (78% of Existing)
University Hall	Room 104	2x4	4 F40 T12	All	58	45
	Room 102	2x4	4 F40 T12	All	62	48
	Room 25	2x4	4 F40 T12	All	62	48
Business Bldg	Room 137	2x4	4 F40 T12	All	60	47
	Room 138	2x4	4 F40 T12	All	67	52
	Room 149	2x4	4 F40 T12	All	38	30
Fine Arts	Room 295	1x4	2 F40 T12	All	52	40
	Room 290	1x4	2 F40 T12	All	60	47
	Room 285	1x4	2 F40 T12	All	50	39

Table 7
Field Test Results of Modified Fixtures

Building	Location	Fixture Size	Lamp No & Type	Lamps On	Average Fc	New fc (78% of existing)
University Hall	Room 106	2x4	4 F40 T12	All	87	68
		2x4	2 F40 T12	Inboard only	45	na
		2x4	2 F40 T12	Outboard only	41	na
Physical Plant	J.Rhodes' Off	2x4	4 F40 T12	All	84	66
		2x4	2 F40 T12	Inboard only	41	na
		2x4	2 F40 T12	Outboard only	45	na

was John Rhodes' office in the Physical Plant Building. The office is 10 ft x 14 ft with light colored walls, ceiling, and floor. The ceiling height is 9 ft. The room contains four, 2 ft x 4 ft, four-lamp lay-in fixtures with side-mounted ballast channels. Since the fixtures were a different configuration and were not representative of the majority of fixtures on campus, it was decided not to modify them. The same three tests were performed as had been done in Room 106 of the University Hall Building. Since the office was proportionately smaller, only five measuring points were used. Test results from both Room 106 and John Rhodes' office are presented in Table 7.

It is interesting to note how the location of the ballast channel affected the outcome of the two tests. In both tests, measurements were obtained to determine the average fc in the room with all lamps on. The New fc levels, based on the audit report, are also presented. In Room 106, where the fixtures have center-mounted ballast channels, the 2 inboard lamp test provided the higher lighting level. The resultant 45fc level is not far below the IES minimum of 50fc. By contrast, in John Rhodes' office, where the fixtures have side-mounted ballast channels, the 2 outboard lamps provided the higher lighting level. It was decided to do further testing on fixtures with center-mounted ballast channels since they represent the majority of fixtures on campus.

Because of the difficulty of modifying fixtures in the field, it was decided that any further testing should be done under more controlled laboratory conditions.

VI. LAB TESTS AT THE ESL LAB

A series of lab tests was designed to compare the light output of fixtures with different combinations of lamp types and locations within the fixture. The Base Case fixture is a 2 ft x 4 ft, four-lamp, 40W T12, lay-in fluorescent fixture, since a major component of the retrofit involves either delamping or modifying the fixtures to accomodate two lamps instead of four.

The test facility is located in the ESL Lighting Calibration Lab at the Riverside Campus of Texas A&M University. The room was originally designed to allow for both footcandle meter calibration as well as testing of various lamp types and lamp locations within a fixture. The test room is 11 ft 7 in by 11 ft 7 in with an 8 ft ceiling height. The walls are painted matte white with both white floor tile and white ceiling tile. Reflectance values for the surfaces would be considered high by IES standards.

Table 8
Summary of Fixture Illumination Tests Performed at the ESL Laboratory

Test No.	No. & Type of Lamps	Lamp Condition	Lamps On	Average Fc
1	4 F40T12	Aged	All	**103**
2	2 F40T12	Aged	Inboard	54
3	2 F40T12	Aged	Outboard	56
4	2 F40T12	Aged	Centered	61
5	2 F42T10	New	Inboard	74
6	2 F42T10	New	Outboard	72
7	2 F42T10	New	Centered	**80**
8	4 F40T12	New	All	**113**
9	2 F40T12	New	Inboard	60
10	2 F40T12	New	Outboard	60
11	2 F40T12	New	Centered	61

Three 2 ft x 4 ft, four-lamp recessed fixtures have been installed in the ceiling and are symmetrical with respect to the room centerlines in both directions. Fifteen measuring points were established on two foot centers in one direction and four foot centers in the opposite direction with respect to the room center lines. A reflected ceiling plan of the test room, including the locations of the measuring points, is provided in Appendix A. At all measuring points, the instrument photocell was placed at the IES workplane height of 30 in from the floor.

The measuring instrument is a combination footcandle/footlambert meter manufactured by the AEMC Corp. of Boston, Mass. It consists of a Model # CL2010F Lightmeter Module and a Model # 2000 Multidisplay. The instrument was last calibrated in July, 1992 and has an accuracy of 0.7% of the reading ±3 counts on the 0-200 Fc scale.

The test sequence began with a set of readings based on four F40T12 lamps in each of the fixtures. This was done to establish a Base Case for comparison with any of the two lamp combinations. Subsequent tests were done with the two inboard lamps on, the two outboard lamps on, and two lamps centered in their respective halves of the fixture on either side of the center-mounted ballast channel.

For the next series of tests two F42T10 lamps were installed in the fixtures. As was performed in the previous series of tests, readings were taken with the two inboard lamps on, the two outboard lamps on, and two lamps centered. A third series of tests was performed using new F40T12 lamps. This was performed because the F40T12 lamps used in the first series had aged approximately 1,664 hours. Since all fluorescent lamps depreciate approximately 10% in lumen output during the first 2,000 hours of operation, the new F40T12 lamps were tested because the F42T10 lamps were also new. This would allow for an accurate comparison of light output. A summary of test results is presented in Table 8.

Several interesting observations can be made from the test results displayed in Table 8. When test #1 and test #8 are compared, the result of lamp lumen depreciation can be observed. In this case, the difference between the average of 103 footcandles for aged lamps and 113 footcandles for new lamps is approximately 10%. It is also seen in tests #4, #7, and #11 that the centered-lamp configuration provides more light output than either the inboard or outboard lamp positions. Of particular note are the results of test #7. The 2 F42T10 lamps in the centered position provide 80 footcandles, which is higher than any other two lamp combination. If test #7 is compared with test #8, it can be seen that two F42T10 lamps, centered in each fixture, provide 80 footcandles, while four F40T12 lamps in each fixture provide 113 footcandles. ***The two lamps produce 71% of the lighting level of the four lamps.***

VII. COST ANALYSIS

A number of manufacturers of ballasts, lamps and reflectors were contacted to obtain cost information for the various components in different lamp, ballast and reflector combinations. This allowed for an analysis that related light output and efficiency to capital investment costs. The manufacturers were told that a study of the cost effectiveness of various ballast, lamp and reflector combinations was underway, and were asked to quote prices on the basis of large volumes. Table 9 presents the results of the prices quoted, but does not include labor.

Table 9
Unit Costs for Light Fixture Components

Item	Quantity	Unit Cost	Total Cost
T10 Lamps for 2-lamp fixture	2	$5.00	$10.00
T10 Socket Bar	2	$1.00	$2.00
T10 Electronic Ballast	1	$25.00	$25.00
T8 Lamps for 2-lamp fixture	2	$1.59	$3.18
T8 Lamps for 4-lamp fixture	4	$1.59	$6.36
T8 Lampsockets for 2-lamp fixture	4	$0.25	$1.00
T8 Lampsockets for 4-lamp fixture	8	$0.25	$2.00
T8 Electronic Ballast for 2-lamp fixture	1	$25.00	$25.00
T8 Electronic Ballast for 4-lamp fixture	1	$31.00	$31.00
Specular Reflector	1	$35.00	$35.00

In a previous section of this report (see Table 5) a number of different lamp and ballast combinations were presented from the standpoint of lumen output and efficacy. Table 9 lists the prices of the components

needed to put together various combinations of lamps, ballasts, or reflectors for retrofit light fixtures. For example, a T10 retrofit would include two T10 lamps, two socket bars to allow for lamp centering, and one T10 electronic ballast. The total cost for these items is $37.00. The magnetic T10 ballast is not considered since it does not qualify for the T.U. Electric Incentive. Another retrofit choice is a T8, two-lamp combination which includes two T8 lamps, four T8 lampsockets, and one T8 two-lamp ballast. The total cost for these items is $29.18. New lampsockets are required since the old ones can create arcing at the lamp-end pins. A T8, two-lamp retrofit that includes a reflector would cost $64.18. A T8, four-lamp retrofit without reflector would cost $39.36. Table 10 summarizes the total costs, less labor, for these combinations.

Table 10
Total Costs for Select Lighting Retrofit Combinations

Combination	Items	Quantity	Unit Cost	Total Cost
2 Lamp T8	T8 Lamp	2	$1.59	$3.18
	Electronic Ballast	1	$25.00	$25.00
	Lampsockets	4	$0.25	$1.00
Total				**$29.18**
4 Lamp T8	T8 Lamp	4	$1.59	$6.36
	Electronic Ballast	1	$31.00	$31.00
	Lampsocket	8	$0.25	$2.00
Total				**$39.36**
2 Lamp T8 w/reflector	T8 Lamp	2	$1.59	$3.18
	Electronic Ballast	1	$25.00	$25.00
	Lampsocket	4	$0.25	$1.00
	Reflector	1	$35.00	$35.00
Total				**$64.18**
2 Lamp T10	T10 Lamp	2	$5.00	$10.00
	Electronic Ballast	1	$25.00	$25.00
	Socket Bar	2	$1.00	$2.00
Total				**$37.00**

VIII. SUMMARY AND CONCLUSIONS

The purpose of this study, as stated in the introduction, was to collect information relating to various combinations of lamp quantities, lumen output, and lamp spacings to determine the most efficient foot-candle levels from 2 ft x 4 ft, four-lamp fixtures, described as the Base Case, that have had two lamps removed. The survey was undertaken, at the request of U.T. Arlington personnel, to determine whether a major lighting retrofit could be completed without the use of specular reflectors, an expensive component of the retrofit.

The survey began with a careful review of the information provided in the original Audit Report. On the basis of fixture tests from the audit report presented earlier in this paper, a base level was established that indicated a fixture retrofitted with two F40T12CW lamps with a specular reflector and magnetic ballast would produce a light output of 78% of existing lighting levels when compared to a four-lamp, F40T12CW fixture. In addition, the Audit Report presented a survey of current footcandle readings in representative classrooms in each of 13 buildings on the U.T. Arlington Campus. A summary of the review of the audit report was presented above in Tables 1, 2, and 3.

The Illuminating Engineering Society was contacted to verify current IES minimum recommended lighting levels for schools and classrooms. Although the current range is **50-75-100 footcandles** (Lighting Handbook, 8th Edition, IESNA, 1993), the trend seems to be for higher lighting levels in college classrooms, as reported by the chairman of the IES School and College Lighting Committee. A revision to the ANSI approved standard, RP-3-88, "Educational Facilities Lighting", will be released next year and will recommend a minimum lighting level of 60 footcandles for college classrooms. A survey was then made on various lamp and ballast combinations available in the marketplace with respect to light output and energy efficiency. The results, presented in Tables 4 and 5, indicate which lamp and ballast combinations comply with Federal laws enacted to save energy.

After verifying that the T.U. Electric incentive would apply to either a high efficiency lamp and ballast retrofit and/or specular reflector retrofit, a series of field tests and lab tests were undertaken for two reasons: First, to get a sampling of classroom lighting levels on the UTA Campus, and second, to determine if lamp locations within the fixture would impact the amount of light output. Results of the field tests and lab tests were presented in Tables 6, 7, and 8.

Since the results of the preliminary field classroom measurements indicated that most of the post-retrofit lighting levels would not meet the current IES minimum of 50 footcandles, let alone the soon to be revised 60 footcandle level for college classrooms, a much larger sampling was scheduled. During the week of 9/20/93 an additional 119 classrooms were surveyed. The sampling included twelve classrooms that had been measured and reported in the Audit Report. Comparative readings were then made with a cosine corrected lab instrument in the Architecture Department at Texas A&M University. The comparitive readings indicated that the instrument used for the UTA field measurements was reading 15% low. Consequently, the field measurements in the classroom survey were increased by 15%. From a total of 119 classrooms surveyed, eighty-one (68% of the total) currently meet the IES minimum level of 50 footcandles. After retrofit implementation, using the Audit Report formula of "78% of Existing", only fifty-one (43% of the total) would meet the current minimum 50 footcandles level. If the revised standard of 60 footcandles for college classrooms is taken into account, then only thirty classrooms (25% of the sample) would meet this standard following retrofit. The detailed results of the survey are presented in Appendix B. These findings were transmitted in writing to UTA Physical Plant personnel.

In order to evaluate the impact of an Energy Cost Reduction Measure (ECRM), the capital investment required must be weighed against energy cost savings. After determining which lamp, ballast and reflector combinations were most efficient, a number of component manufacturers were contacted so as to obtain competitive pricing for a cost analysis. The results of this analysis were presented in Table 9 and 10 along with a brief discussion of the comparative prices of each combination.

In summary, the fundamental component for determining how to best implement a lighting retrofit at UTA is a full, comprehensive survey of existing lighting levels, as well as a comparison of the capital investment required for various combinations of lamps, ballasts, and/or reflectors to satisfy the IES minimum of 50 footcandles. If a classroom currently has a lighting level of 64 footcandles, then according to the 78% of Existing lighting level as presented in the Audit Report, the minimum level of 50 footcandles would be met. This is based on the Case 3 test as reported in Table 2. However, the current bid specifications call for a combination of two F32T8 lamps with electronic ballast and specular reflector. This would result in 79% of existing lighting level (per Table 2) or a current level of 65 footcandles. The capital investment required per fixture would be $64.18.

Based on the lab tests conducted at Texas A&M, a two-lamp F42T10 fixture with lamps centered would produce 71% of the lighting level of a four-lamp fixture. This means that a classroom with a current level of 71 footcandles would meet the IES criteria after retrofit. The unit cost per fixture would be $37.00. In some instances, where the current classroom level is close to 50 footcandles, it might be advisable to retrofit with four T8 lamps and electronic ballast at a cost of $39.36. This would reduce lighting output by 2% but would reduce energy input by 34%. Table 11 is a summary that takes into account lamp/ballast performance compared with capital expenditure with respect to meeting IES minimum foot-candle levels. Based on both field and lab tests, fc criteria are presented for current levels to meet the post-retrofit requirements of 50 footcandles.

Table 11
Lamp/Ballast Performance Compared with Capital Investment

Lamp/Ballast	Cost	% of Existing fc level	% Energy Reduction	Current fc required
2 lamp T8 w/electronic ballast & reflector	$64.18	79	67	65
2 lamp T10 w/electronic ballast	$37.00	71	60	71
4 lamp T8 w/electronic ballast	$39.36	98	34	51

It can be seen from Table 11 that the lighting engineer has a number of choices to make when it comes to weighing capital investment against energy use reduction, considering current lighting levels in rooms. In some instances, the four-lamp T8 with electronic ballast fixture might be the best choice since lighting levels are decreased by only 2% whereas energy consumption is cut by 34%.

We recommend that a full, comprehensive survey be undertaken at UTA, based on the above findings, before a final decision is made regarding the lighting retrofit.

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