ESL-TR-88/10-01

REDESIGN OF LIGHTING FIXTURES FOR THE TEXAS DEPARTMENT OF CORRECTIONS

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October 31, 1988

ACKNOWLEDGEMENTS

This report is an account of work sponsored by the Texas Governor's Energy Management Center under the "State Energy Project" at Texas A&M University under contract number 8112. The guidance and technical input provided by Malcolm Verdict and James White of the Governor's Energy Management Center have been extremely valuable. The testing reported herein would not have been possible without the cooperation and assistance of Bill Beil and other personnel at the Texas Department of Corrections. The contributions of all are gratefully acknowledged.

EXECUTIVE SUMMARY

Over 100 tests of potential design modifications for the cell light fixtures used by the Texas Department of Corrections have been conducted. As a result of these tests, the following recommendations are made:

1. Turn diffuser material so prisms face cell.
2. Enlarge diffuser opening to 16 by 46 inches.
3. Replace 1/2-inch hardware cloth by #3 stainless cane weave with 2-inch mesh, painted white.
4. Replace ballasts with Advance R-2S40-TP Mark III or equivalent.
5. Replace blankets with light colored blankets.

6a. Use fixture with four 34 watt tubes if no allowance for fixture degradation is deemed acceptable;

6b. Use fixture with three 40 watt high efficiency tubes and reflector if 10%-15% margin above 20 fc is needed;

6c. Use fixture with four high efficiency tubes if 20% margin above 20 fc is considered necessary.

Implementation of these recommendations will result in reduced construction cost of $91,418 and annual operating savings of $88,910 if recommendations 1-5 and 6a are implemented at Amarillo and Gatesville. Use of recommendations 1-5 and 6b will increase first cost by $22,592, but annual operating savings also increase to $98,928 while 6c would provide first cost savings of $67,606 and operating savings of $73,882 annually.

Additional maintenance savings will be realized in each case since the fixtures recommended above use tubes with 20,000 - 24,000 hour operating lifetimes instead of the 12,000 hours of the base case tubes.

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INTRODUCTION

Energy standards for state owned buildings are currently being developed. However, state construction programs in progress will result in major new construction before the energy standards can be completed and implemented. In the interim, to ensure that sound energy design practices are followed, the Energy Management Center has initiated a program as part of the State Energy Project at Texas A&M to provide energy review and design assistance for current construction projects of state agencies. The largest projects are within the Texas Department of Corrections. Two 2250 bed prisons have recently been designed and additional units are scheduled for the near future.

The design review was initiated in November, 1987 and final plans for the two 2250 bed units were due in early January, 1988. The review was scheduled in two phases: a rapid review of the overall energy design features and systems was completed in December, 1987; the second phase has conducted a redesign of the cell lighting fixtures and is currently testing energy efficient shower heads. This report gives the results of the testing and redesign of the lighting fixtures.

CELL LIGHTING FIXTURES

During the survey of the prison plans, examination of the cell lighting system showed that the lighting power was approximately 2.5 watts/ft^2, but observation of the cells showed that lighting levels were relatively low. The lighting for each cell is provided by a four-tube fluorescent fixture mounted behind a stainless steel chase wall as shown in Figures 1a and 1b; the wash basin, toilet, mirror and electrical

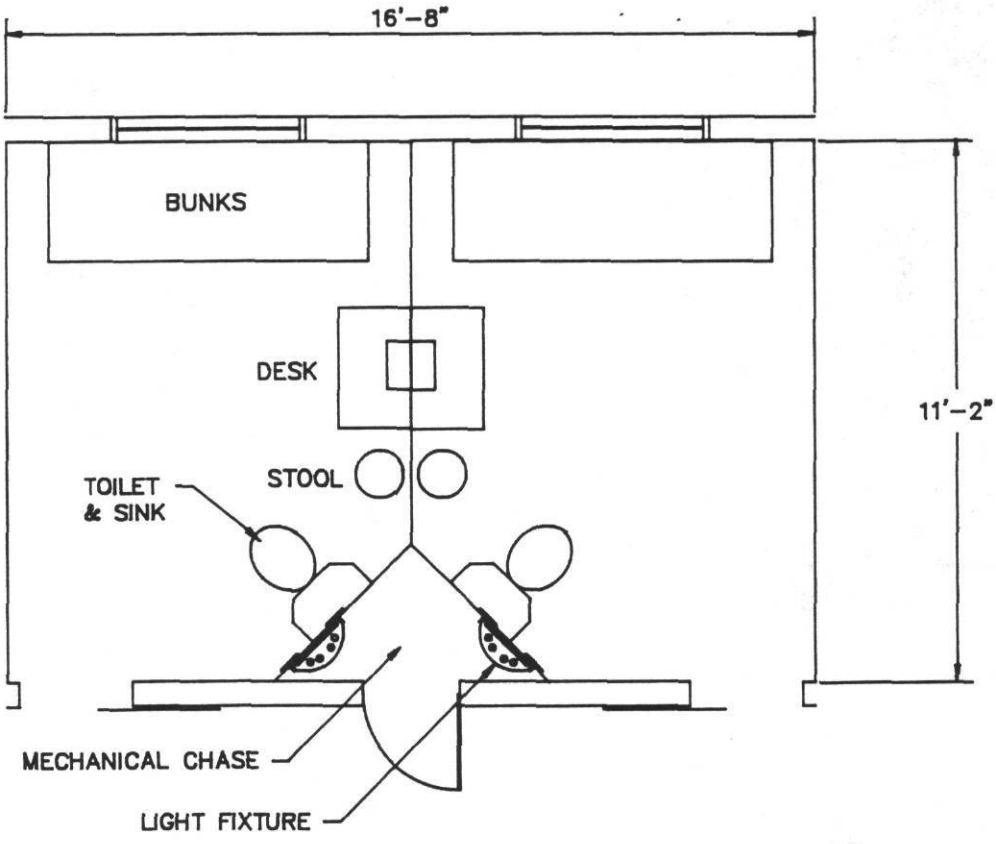

Figure 1A. Floor Plan of General Population Cells.

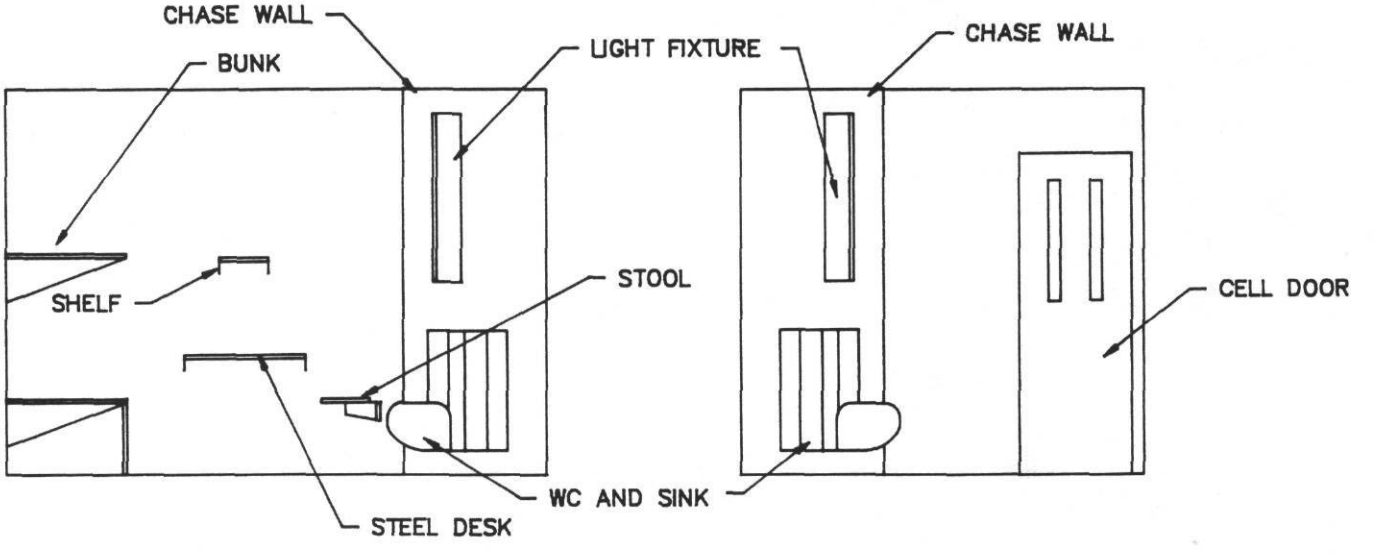

Figure 1B. Elevations Showing Light Fixture in Cell. Note that it is Mounted Diagonally across the corner of the Cell.

outlet are also mounted on the chase wall. The unit is mounted in one corner of each cell, allowing all of the items noted to be serviced from a plumbing chase behind the unit.

The lighting fixture uses four high output 60 watt tubes (F48T12CW/HO) to achieve a nominal 20 fc light level on the lower bunk. Maintenance personnel dislike the high output tubes, since they have a mean lifetime of only 12,000 hours compared with the 20,000 hours of normal tubes and cost about three times as much. They were initially chosen to meet minimum illumination levels specified for the cells while allowing the fixture to be installed entirely outside the cell living area to increase security.

The lighting fixture consists of: (1) an 18 Ga sheet-steel troffer, painted with high density, high reflectivity white paint; (2) four 60 watt tubes; (3) 16 Ga stainless steel hardware cloth with a half-inch square mesh; and (4) a 1/2-inch Lexgard* laminated diffuser with the diffusing prisms mounted inward, facing the hardware cloth and tubes as shown in the sectional view of Figure 2. The diffuser/hardware cloth assembly is welded to the back of the chase wall as shown in the figure.

The Lexgard* was specified to provide a highly secure glazing material, while the hardware cloth backing is provided for additional security.

DESIGN EVALUATION

A full scale mock-up of a two-man general population cell from the Michaels Unit was built by Department of Corrections personnel and

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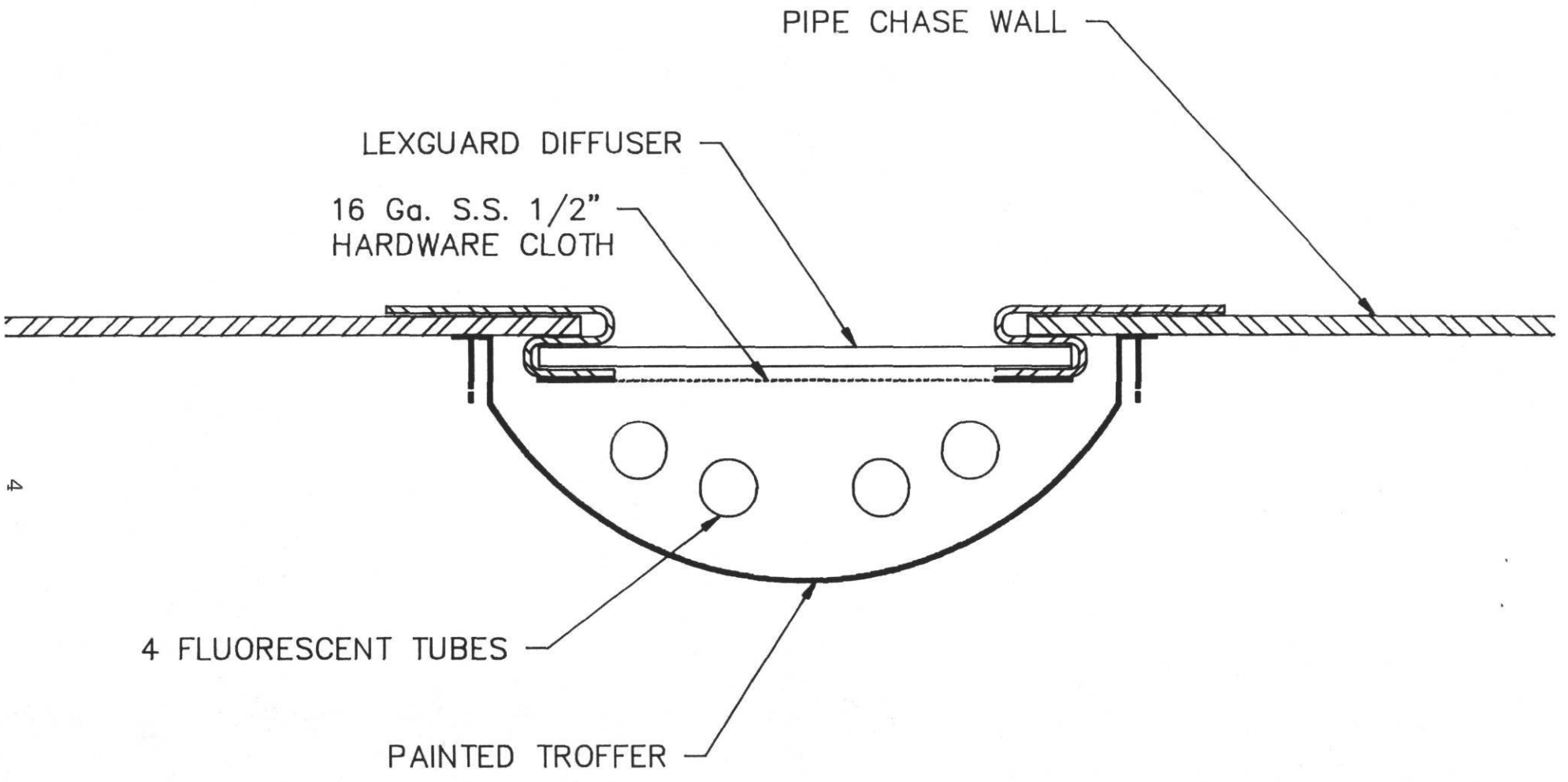

Figure 2. Sectional View of Diffuser and Hardware Cloth in Chase Wall.

installed at the Energy Systems Laboratory for testing of the lighting fixtures. A similar mock-up was built at the Coffield Unit.

Preliminary Measurements

The initial design objective was to decrease lighting power by at least 33% while providing the same amount of light as the original design. Hence initial measurements were made with the following four combinations of fluorescent tubes:

1. 4 - 60W 4150 lumen tubes (F48T12CW/HO)
2. 4 - 40W high efficiency 3700 lumen tubes (Phillips F40AX35Adv.X)
3. 4 - 40W standard 3150 lumen tubes (F48T12CW)
4. 2 - 60W 4150 lumen tubes plus a focusing reflector fabricated by Omega Energy

These measurements investigated the impact of the diffuser orientation, hardware cloth and aperture size at 15 locations throughout the cell as shown in Figure 3. Measurements were made 30-inches above the floor except for positions measured on bunk surfaces. The position at the head of the lower bunk (position 3) was found to be most important since it is the reading position which receives the least light. Measurements were made with the measurement surface: (1) horizontal, (2) 60 degrees from horizontal and facing the foot of the bunk, and (3) 60 degrees from horizontal and facing the head of the bunk.

Table 1 shows that 7-27 percent more light reached the measuring surface when the prisms faced the cell than when they faced the fixture (as installed in the original design), except when the focusing reflector was used. Then it was advantageous for the prisms to face the fixture. A complete set of the measurements used for Tables 1-4 are provided in Appendix A.

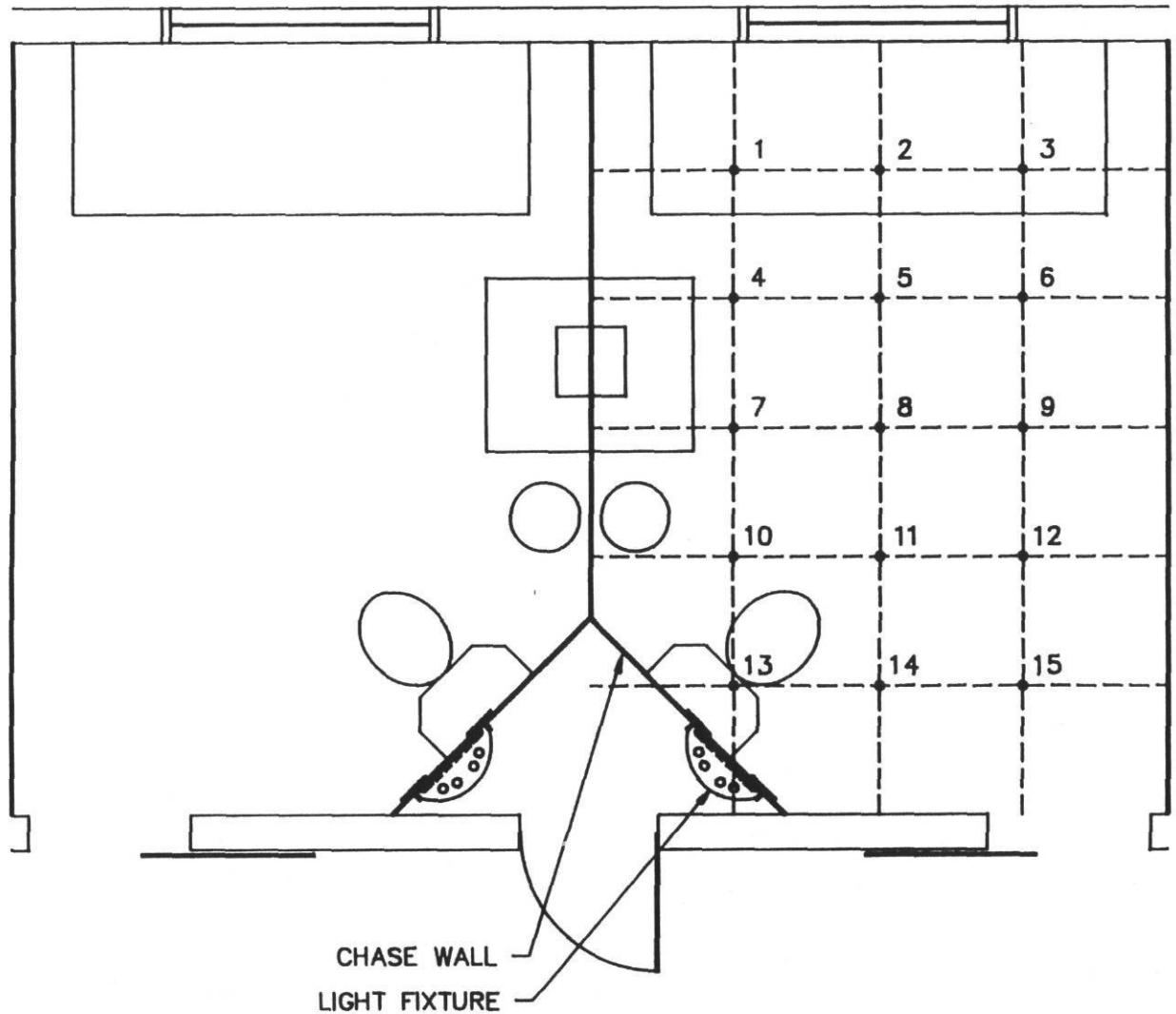

Figure 3. Measurement Locations.

TABLE 1. Ratio of light level with diffuser prisms facing cell vs prisms facing lighting fixture at bottom bunk for three measurement orientations and four different sets of fluorescent tubes.

Configuration	Measurement Direction		
	(1) Horiz.	(2) 60° to foot	(3) 60° to head
4 - 60	1.18	1.07	1.13
4 - 40 high eff.	1.16	1.23	1.22
4 - 40 stand.	1.26	1.21	1.27
2 - 60 plus refl.	0.89	0.85	0.93

The use of the hardware cloth substantially decreased light levels in every case measured as shown in Table 2. Sixteen to 48 percent more light reached the measurement surfaces when the hardware cloth was removed. However, replacing the hardware cloth with white-painted #3 stainless cane weave with a 2x2-inch mesh size produced a notable improvement over the hardware cloth as shown in Table 3. It also increases security.

TABLE 2. Ratio of the light reaching the head of the bunk without the hardware cloth in place to that with hardware cloth in place.

Configuration	Measurement Direction		
	(1) Horiz.	(2) 60° to foot	(3) 60° to head
4 - 60	1.34	1.30	1.43
4 - 40 high eff.	1.48	1.40	1.42
4 - 40 stand.	1.19	1.20	1.16
2 - 60 plus refl.	1.27	1.32	1.33

TABLE 3. Ratio of the light reaching the head of the bunk with white #3 cane weave vs 1/2" hardware cloth.

Configuration	Measurement Surface Orientation	
	(1) Horiz.	(2) 60° to foot
4 x 40 W high eff.	1.30	1.26
4 x 40 W stand.	1.39	1.42

Examination of the light fixture also revealed that the opening of the fixture measured 16x48 inches while the diffuser dimensions were 13x46 inches. Table 4 shows that using a larger diffuser increased the light levels by about 20 percent. These measurements were made with four 60W tubes, prisms facing the cell, and without hardware cloth.

The data shown makes it obvious that, in general, the prisms should face the cell, the #3 white-painted stainless cane weave should be used and the diffuser opening should be enlarged. Ideally, the diffuser opening should be 16x48 inches. However, the standard width Lexgard sheet is 48-inches, which indicates an opening length of 46 inches to allow for an edge engagement of 1-inch. Likewise, a standard 48x72-inch sheet can be cut to 18-inch width with no waste, permitting a 16x46-inch opening.

TABLE 4. Dependence of light reaching the head of the bunk on aperture size.

Aperture	Measurement Surface Orientation		
	(1) Horiz.	(2) 60° to foot	(3) 60° to head
43 x 13 inches	25.6	27.3	24.7
48 x 16 inches	31.8	32.2	30.1
Ratio	1.24	1.18	1.22

Measurement Procedures

The initial measurements were made using a variety of positions as noted. Standards of the Illuminating Engineering Society of North America (IES) were examined and adopted where applicable for all subsequent measurements. There is no standard measurement procedure for reading in bed, so a procedure consistent with IES procedures was adopted. The procedures used are summarized below.

Measurement Locations

Lighting measurements were taken at the three reading locations within the cell which were: 1) the cell desk, 2) the lower bunk, and 3) the upper bunk. Task planes for each location were adopted as follows:

Desk:
The desk is 30 inches above the cell floor and has an area of 873 square inches (24 1/2 by 36 inches). The task plane adopted is 12 by 14 inches. Measurements were taken at the center of this plane with the metering surface at desk level in the plane of the desk.

Lower Bunk:
The lower bunk is 18 inches above the floor and has an area of 2325 square inches (31 by 75 inches). The task plane adopted is 12 inches above the mattress. Measurements were taken with the metering surface horizontal (LB FLAT) and at 45 degrees from the vertical with the meter facing toward the wall at the head of the bunk (LB 45).

Upper Bunk:
The upper bunk is 54 inches above the cell floor and has an area of 2212.5 square inches (29 1/2 by 75 inches). The task plane and measurements taken are similar to those for the lower bunk and are designated UB FLAT and UB 45.

Measurement Equipment and Conditions

An AEMC Model 814 Lightmeter calibrated against an NBS traceable standard in March 1988 was used for the measurements. All fluorescent tubes used were seasoned for 100 hours (unless otherwise specified) and were burned for at least 1 hour prior to measurements as specified by IES standards. The measurement technician wore a white laboratory coat, or white shirt and pants and was the only person in the cell while measurements were taken. He took measurements while standing or kneeling in a position such that he did not cast a shadow on the task plane nor reflect light directly onto the task plane during measurements. The bunks were furnished with standard TDC mattresses, sheets and blankets unless otherwise specified.

A complete set of the measurement specifications is given in Appendix B.

Measurement Results

The remaining measurements incorporated the findings of Tables 1-4 and concentrated on identification of combinations which provide more light than the present design while using less energy. It was soon noted that the standard TDC black blankets cut the light level appreciably at the critical lower bunk reading position, so tests were also conducted using a medium blue blanket and a bone-colored blanket. Results of additional tests using the white sheet only or only the mattress are given in Appendix C.

Table 5 shows the results of these measurements. The values shown in the table are an average when multiple measurements were made for the same configuration. Use of a lighter colored blanket can increase the measured light level on the task plane in the LB-45 position by up to 10 percent. Most of the combinations shown nominally meet the 20 fc requirement based on the stringent test procedure used and all of the configurations shown greatly exceed the light levels of the base case. Table 6 shows the ratio of the light level measured for each configuration to that provided by the base case. The cases tested provide 30 percent to 81 percent more light than the base case while they required as little as 39 percent as much power to operate. The fixture power levels given in the tables are based on use of two Advance RF-2S60-TP high output ballasts (25 watts each) with the base case fixture and two Advance R-2S40-TP Mark III ballasts (6 watts each) with the other fixtures. The complete data on which these tables are based as well as measurements at the other locations are provided in Appendix C.

The lighting performance at the other reading positions was always higher than that on the lower bunk, and the relative amounts of light generally tracked those shown in Tables 5 and 6 quite closely. This is illustrated in Figure 4. It should be noted that the 3-tube reflector was optimized for the horizontal lower bunk reading. It appears that similar optimization for the LB-45 position would increase the light level by approximately 5 percent.

Economic Analysis

The systems can be grouped in six configurations for cost analysis as shown in Table 7. This analysis is based on the use of state

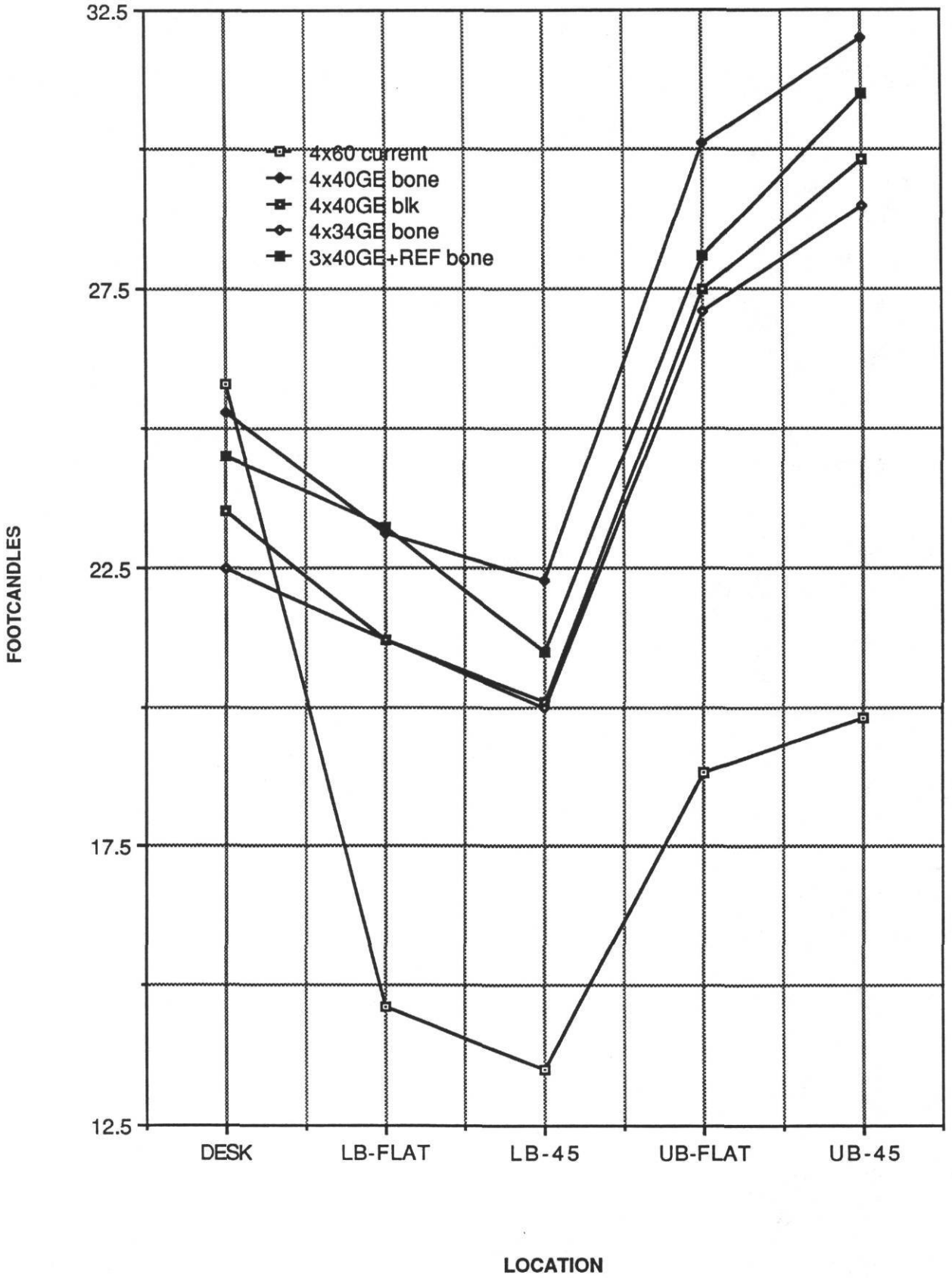

Figure 4. Light Level as a Function of Measurement Location for Five Configurations

TABLE 5. Light measured at LB-45 position in (fc) and power (watts) for 25 configurations.

Light Config.	Blanket Color			Fixture Power (incl. ballast)
	Black (stand.)	Med. Blue	Bone	
4x60 Base	13.5	--	--	290
4x40	20.2	21.5	22.2	172
4x40 High Eff.	22.6	--	(24.8)*	172
2x40+2x34	--	--	20.8	160
4x34	18.4	19.0	20.0	148
4x34+Refl.	21.6	22.1	(23.3)*	148
3x40 Refl.	19.2	19.6	20.2	132
3x40 High Eff. +Refl.	21.6	20.7	22.6 (23.7)*	132
3x34+Refl.	--	17.5	18.5	114

*Extrapolated values.

TABLE 6. Ratio of light measured at LB-45 position and fixture power for 24 configurations to that measured for the base case.

Light Config.	Blanket Color			Fixture Power (incl. ballast)
	Black (stand)	Med. Blue	Bone	
4x40	1.50	1.59	1.64	0.59
4x40 High Eff.	1.67	--	--	0.59
2x40+2x34	--	--	1.54	0.55
4x34	1.36	1.41	1.48	0.51
4x34+Refl.	1.60	1.64	--	0.51
3x40 Refl.	1.42	1.45	1.50	0.46
3x40 High Eff. +Refl.	1.60	1.53	1.67	0.46
3x34+Refl.	--	1.30	1.37	0.39

TABLE 7. Economic comparison of base case and alternate lighting fixtures - Gatesville.

			Cost for 1452 fixtures in 2250 man prison		
	Fixture Cost	First Cost	Annual Operating Cost	First Cost Savings	Operating Cost Savings
Base Case	$67.36	$97807	$96428	---	---
4x40 W High Eff	$44.08	64004	57192	$33803	$39236
4x40 W Standard	$35.88	52098	57192	45709	39236
4x34 W	$35.88	52098	49211	45709	47217
4x34 W + Refl	$70.88	102918	49211	(6490)	47217
3x40 W High Eff & Refl	$75.14	109103	43891	(11296)	52537
3x40 W Standard plus Refl	$68.99	100173	43891	(2366)	52537

contract prices for all items except the Philips F40AX35 Advantage X lamps and the focusing reflectors. The lamps were estimated to cost 10 percent more than the F48T12CW/HO lamps currently used based on the statement of the Philips representative that they "will have a user cost price approaching that of the F48T12/CW/HO lamp." The reflector cost was based on estimates provided by Omega Energy. All analysis assumes use of the Advance R-2S40-TP Mark III ballasts (6 watts each) rather than the standard RQM-2S40-TP ballasts (14 watts each) since the incremental cost of $2.04 is recovered in a little more than one year from reduced operating costs. This table does not include light levels. A complete listing of assumptions used is provided in Appendix D.

Table 8 summarizes the economics and light levels for several systems, all of which are assumed to use the bone-colored blanket or equivalent. The fixture with the four 34 watt tubes is the obvious choice if its light output of 20.0 fc is considered adequate. This is 48 percent greater than the current fixture, the first cost is $45,709 less than the base case (as low as any system tested), and operating savings exceed $40,000 per year in both locations. The only configurations with lower operating cost are those with three tubes and the reflector. The system with 3 40 watt standard tubes provides the same amount of light, but the simple payback on the additional first cost is about nine years, so it is not recommended. Thus the 4x34 watt fixture is recommended if the current test standard is considered stringent enough that no allowance for fixture degradation is necessary.

TABLE 8. Economic comparison with light levels at lower bunk of preferred systems. All assume use of light colored blankets (e.g. bone).

Configuration	Light Level (fc)	First Cost Savings	Operating Cost Savings	
			Gatesville	Amarillo
Base Case	13.5	--	--	
4x34 W (bone)	20.0	$45709	$47,217	$41,693
4x40	22.2	45709	39236	35646
3x40 Ph+Refl.	23.7	(11296)	52537	46391
4x40 Ph	24.8	33803	39236	34646

If a system is chosen which provides an allowance for degradation, the system with three 40 watt high efficiency lamps and the reflector is recommended. It provides a margin for degradation of almost 20 percent, has an operating cost which provides a payback of less than five years relative to the four standard tubes, and provides more light. The system with four high efficiency tubes provides slightly more light, and the payback of the three-tube fixture with reflector is 3-4 years relative to this fixture. The reflector should also have less degradation with time.

CONCLUSIONS AND RECOMMENDATIONS

Based on the measurements and analysis presented, the following recommendations are made:

1. Turn Lexgard diffuser material so prisms face cell.
2. Enlarge diffuser opening to 16 by 46 inches.
3. Replace 1/2-inch hardware cloth by #3 stainless cane weave with 2-inch mesh, painted white.
4. Replace ballasts with Advance R-2S40-TP Mark III or equivalent.
5. Replace blankets with light colored blankets.

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