Fundamentals Of Lighting Cost Analysis

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ALTHOUGH lighting performance characteristics are the most important factor in the selection of a lighting system, cost is nearly always a consideration. Often, when the lighting performance of different systems is similar, cost becomes the deciding factor. Thus, accuracy and uniformity in cost analysis methods are highly desirable so that analyses by different individuals may be readily and fairly compared.

Of course, cost comparisons exclude considerations of relative lighting quality, which is of equal importance to quantity. Reports showing favorable economy for a lighting system which fails to provide comparable comfort should be accompanied by suitable explanations.

Cost Analysis Objectives

The fundamental cost elements by which different lighting systems must be compared are initial cost and operating cost. While either element may be a dominant factor in the final selection, it is usually desirable to combine these two charges into some type of "total cost" indicator.

The computation of initial, operating and total annual cost for various systems considered for a given interior must be based on certain common assumptions, if the systems are to be fairly compared. Some of the important considerations are:

1. Equal illumination results — since different systems may not produce equal illumination levels in service, all costs should be equated to an equal maintained footcandles basis.
2. Equal rates in amortizing the initial investment and allowing for interest, taxes and insurance should be used.
3. Operating conditions — such as electrical energy rate, burning hours per year and starting frequency of the lamps should be equal for the systems being considered.
4. Cleaning schedule should be appropriate to each type of system.
5. Uniform labor rates among systems should be used for estimating the cost of installation, cleaning and relamping.

Proposed Uniform Method

Table I is a cost analysis showing the effect different light sources might have on lighting costs in an industrial installation where the mounting height of the lighting equipment is 25 feet. The table uses the procedure suggested, and shows the various items of information which must be assembled.

The analysis is divided into four principal sections.

Basic Data

Section A is concerned with the factors which must be established before costs can be determined. Most of these eight items are self-explanatory, but the following comments are pertinent:

Item 3 — For fluorescent lamps, use the manufacturer's published average wattage values rather than values which are often nominal. Actual wattage on most general lighting fluorescent lamps is lower than the rounded values usually quoted.

Item 5 — The coefficient of utilization should be determined for each luminaire considered, and for the actual room size, and room-surface reflectances.

Item 6 — Maintenance Factor should be realistically based on (1) mean lamp output, (2) mean depreciation due to dirt collection on lamps and reflecting elements of luminaire (as estimated from the cleanliness of the air, the design of the luminaire and the assumed cleaning schedule) and (3) loss of illumination caused by gradual darkening of room surfaces.

Item 8 — These are the multiplying factors that equate the systems to a common illumination value. The development and use of these factors provide the quick and easy comparison of relative Initial (Item 14), Operating (Item 22) and Total Annual Cost (Item 23).

Since the primary interest is in *relative* costs, much of the analysis can be made on the convenient and simple "Per Luminaire" basis, *with proper adjustment as mentioned for equal illumination results.* This eliminates the need for considering the illumination level or number of luminaires at this point. Later a simple method is shown for converting the relative values to actual costs applicable to a specific installation.

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TABLE I.—Cost Analysis. Industrial Lighting Systems — 25-Foot Mounting Height.

	Luminaire Description (Porcelain enamelled steel reflectors)	I — Fluorescent 4 85-watt T17 Std. Cool White 4-lamp ballast 265-volt primary		II — Mercury 1 400-watt E-H1 2-lamp ballast 230-volt primary		III — Filament 1 1000-watt PS-52 120 volts	
	Basic Data						
	1. Rated initial lamp lumens per luminaire	17,600		20,000		21,500	
	2. Lamp life	7,500		(e) 3000	4000	1000	
	3. Average watts per lamp	82		400		1000	
A	4. Watts per luminaire (includes ballast watts)	364		430 (f)		1000	
	5. Coefficient of utilization (a)	.62		.59		.59	
	6. Maintenance factor (b)	.65		.65 (g)		.65	
	7. Effective maintained lumens per luminaire (1 × 5 × 6)	7090		7675		8250	
	8. Relative number of luminaires needed for equal maintained footcandles	1.00		.924		.860	
	Initial Costs						
	9. Net luminaire cost (estimated)	$63.00		$25.50		$ 8.60	
	10. Installation (c)	$18.00		$17.00		$11.00	
	11. Net initial lamp cost including tax (estimated)	$ 8.30		$13.60		$ 2.50	
B	12. Total initial cost per luminaire	$89.30		$56.10		$22.10 (h)	
	13. Annual owning cost per luminaire 15% of (9 + 10)	$12.15		$ 6.40		$ 2.95	
	14. Relative initial cost for equal maintained footcandles (12 × 8) / (12 × 8) for column I	100%		58%		21% (h)	
	Annual Operating Costs						
	15. Burning hours per year	2500	4000	2500	4000	2500	4000
	16. Annual energy cost (4 × 15 × rate in c per KWH) / 100,000 — 1c per KWH	$ 9.10	$14.60	$10.75	$17.20	$25.00	$40.00
	2c per KWH	$18.20	$29.20	$21.50	$34.40	$50.00	$80.00
	3c per KWH	$27.30	$43.80	$32.25	$51.60	$75.00	$120.00
	17. Number of lamps replaced per year (15 × no. lamps per unit) ÷ Item 2	1.33	2.14	0.83	1.00	2.50	4.00
C	18. Lamp cost (17 × net price per lamp including tax)	$ 2.75	$ 4.45	$11.30	$13.60	$ 6.25	$10.00
	19. Labor cost of lamp replacements	$ 1.25 (d)	$ 2.05 (d)	$ .65	$ .75	$ 1.85	$ 3.00
	20. Cost of cleaning twice per year	$ 1.80	$ 1.80	$ 1.00	$ 1.00	$ 1.00	$ 1.00
	21. Total annual operating cost per luminaire (16 + 18 + 19 + 20) — 1c per KWH	$14.90	$22.90	$23.70	$32.55	$34.10	$54.00
	2c per KWH	$24.00	$37.50	$34.45	$49.75	$59.10	$94.00
	3c per KWH	$33.10	$52.10	$45.20	$66.95	$84.10	$134.00
	22. Relative annual operating cost for equal maintained footcandles (21 × 8) / (21 × 8) for column I — 1c per KWH	100%	100%	147%	131%	197%	202%
	2c per KWH	100%	100%	133%	123%	212%	215%
	3c per KWH	100%	100%	126%	119%	218%	221%
	Total Annual Costs						
D	23. Relative total annual cost for equal maintained footcandles (13 + 21) × 8 / (13 + 21) × 8 for column I — 1c per KWH	100%	100%	103%	103%	(h) 118%	140%
	2c per KWH	100%	100%	104%	104%	148%	168%
	3c per KWH	100%	100%	105%	105%	165%	183%

(a) For room index D — 50% ceiling, 30% walls.

(b) Includes mean lamp depreciation and mean dirt depreciation during life, with two cleanings per year.

(c) Does not include wiring costs.

(d) Includes one starter replacement (at 50c) for every two lamps replaced.

(e) Rated life at 5 and 10 hours per start, respectively.

(f) Ballast watts and cost given are half of 2-lamp values.

(g) Average for lamp lives given in item 2.

(h) Wiring requirements of filament lighting systems are much greater than for fluorescent or mercury systems. This should reflect in substantially higher initial (and, therefore, total annual) cost than shown here.

Initial Cost

The next step is to establish the net costs of procuring and installing the different systems. This is done in Section B. The following suggestions may be helpful:

Item 10 — Local contractors or the plant or building electrician can supply an estimated average charge per luminaire for hanging. These charges will depend on such factors as height, whether hung individually or in continuous rows, and other aspects of the installation.

In many analyses, complete wiring costs must be calculated in addition to fixture installation costs. No set rules can be given for estimating wiring costs per KVA — almost every case must be computed individually. Except where there is a great difference in the efficiency of the system (as in filament *vs* fluorescent lighting) wiring costs for lighting can be expected to be similar, and to have little effect on the net result, particularly since the amortization period for wiring is usually very long (often 30 years — thus a much lower amortization rate than for the lighting equipment). When systems do differ greatly in efficiency and wiring costs are not shown in the economic analysis, attention should be called to the probable increased cost of energy distribution for the less efficient system.

Item 11 — Lamp costs are shown to indicate the total "out-of-pocket" initial investment, even though they are later charged as an operating expense item.

Item 13 — As stated earlier, total lighting cost should be weighted with an appropriate portion of the initial lighting investment. Whenever an established accounting procedure suggests a reasonable figure to be used on an amortization rate, it should be followed. If there is no set procedure, as is often the case, the use of a 15 per cent write-off rate is suggested. Typically, this might represent amortizing the lighting system in 10 years, at 10 per cent per year, plus 5 per cent for interest, taxes, and insurance.

Note that lamp cost is not included in the write-off.

Annual Operating Cost

Section C gives the various operating charges per luminaire of each system under consideration. Annual energy cost, total operating cost and relative annual operating cost can each be a single value if burning hours per year and average cost of electric energy are known. In many cases, however, exact values are not known. Under the latter circumstances, the use of 2500 and 4000 burning hours per year (typical for one-and two-shift operation respectively in factories) and 1, 2, and 3 cents per kwh (typical of the range of energy rates encountered) is suggested.

Total Annual Cost

The total annual cost per luminaire is obtained by adding items 13 and 21. The sum for each system is multiplied by Item 8 to equate for equal illumination and then related to the reference system, giving the *relative* total annual cost. Most users will have greatest interest in this figure, although some who are budgeting either capital investment or operating charges may be more concerned with one of those two values. Of course, the most economical lighting system from the standpoint of over-all cost is not necessarily the one with either the lowest initial cost or the one with lowest operating costs.

Estimating Actual Dollar Costs

The conversion from the relative costs given in Table I to actual dollars for a specific installation of similar type is readily accomplished. These steps are involved for each system.

1. Divide the effective maintained lumens per luminaire (Item 7) by the footcandle level desired in service. The result is the number of square feet of lighted area per luminaire. This value determines the spacing.
2. Divide the total square feet of the area to be lighted by the square feet per luminaire determined in Step 1 above. This gives the number of luminaires needed for the particular footcandle level in service, and will likely be a fractional quantity.
3. Correct for the number of luminaires to be actually used. In large areas, this answer will be close to that obtained by Step 2 above. In smaller interiors, the relation of room dimensions to luminaire length and orientation may mean the use of slightly more or fewer units in order to achieve a desirable layout and proper appearance of the lighted room.
4. To obtain actual costs in dollars:
   a. Initial cost—multiply Item 12 by number of luminaires
   b. Annual owning cost — multiply Item 13 by number of luminaires
   c. Operating cost — multiply Item 21 by number of luminaires
   d. Total annual cost — add (b) and (c)

It should be noted that comparisons of total annual cost (in dollars) obtained from 4(d) will not be for identical footcandle levels if the number of luminaires computed in Step 2 above is different from the number of luminaires actually used (Step 3).

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In addition to providing a convenient method for estimating costs and comparing systems, such analyses are useful in many other ways. They can be used to determine the effect of variables such as energy cost, lamp depreciation rate, frequency of cleaning, and whether a group or spot replacement program for changing lamps is more economical. It is hoped that use of a uniform method for making and presenting such analyses will help bring greater attention to these important factors of lighting costs, with resultant benefit to lighting practice.

DISCUSSION

JOHN J. NEIDHART*: Any attempt to establish some uniformity in the methods by which we present lighting data and analyses to users of lighting equipment is a welcome one, and I want to add my support to the authors in their general objective.

I am not entirely satisfied, however, with their omission of wiring costs as a part of Item 10. I agree that the effect on the net result will generally be negligible except in cases where the systems being compared differ greatly in efficiency. It happens, however, that a comparison of such systems is

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more likely to be required than a comparison of systems nearly equal in efficiency. The very example that the authors have used for Table I compares sources differing greatly in efficiency. In this instance the footnote reference to that fact is satisfactory since the addition of wiring cost accentuates the difference. There are many cases, however, where the incandescent system may falsely appear to be more economical than the systems with which it is being compared because of the omission of wiring costs. A footnote explanation in such an instance would still leave the comparison clouded with doubts.

Admittedly, wiring costs are very difficult to determine and will vary throughout the country. There is very little data available today on these costs, and it seems to me that each of us should direct his efforts toward obtaining representative wiring costs for his locality. These costs should include all costs back to the panelboard. I know that they can be obtained because we have worked them out with contractors on many occasions. If we obtain and exchange such information we can all benefit.

If wiring costs are included, it will be necessary to determine the actual lighting layout for a given illumination level as a part of the basic data. Having done this it then becomes practical to base the comparison upon the entire systems rather than upon individual luminaires. Comparisons of total costs of any of the items will be thereby facilitated, and I think that these total costs are what the user wants to compare. Any differences in illumination should, of course, be removed in a final line comparing the total relative annual cost per footcandle.

G. W. BEALS*: This paper is of interest because there is an urgent need for a standard method of preparing cost analyses that can be followed uniformly by lighting engineers. Such a standard method must be complete in critical data, fair in its comparisons, and have enough detail to indicate the calculation basis selected where more than one commonly used procedure exists. Most previous lighting analyses have not been taken too seriously because they failed in one or more of the foregoing essentials. This proposed method also fails by its indifferent treatment of wiring costs as an item of initial costs.

There can be no question that wiring cost is a part of total initial cost — it is always a major item and often the largest item. It is a critical item in a tabulation such as Table I, because it indicates the calculation basis where more than one commonly used wiring procedure exists. It cannot be omitted as in Item 10 of the table and certainly Item 12 is not total initial cost. It follows that Annual Owning Cost Item 13 and Relative Cost Item 14 are likewise incorrect and the comparisons unfair. It is far better to add any reasonable estimate of Wiring Cost per Luminaire to each column than to omit the item for the inadequate reasons given in the text.

Table I omits Wiring Cost per Luminaire, and on that basis shows that the mercury system of column 2 has a Total Initial Cost per Luminaire that is only 58 per cent of that of the fluorescent system of column 1. The incandescent system of column 3 is 21 per cent, with a footnote advising that this value is low. To a buyer with a limited budget, Total Initial Cost could well be the dominant factor in his selection, and the comparison shown in Items 12, 13 and 14 would give him a totally wrong impression.

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Assume that the Wiring Cost per Luminaire is $50 per outlet, *i.e.*, the cost of materials and installation labor of providing outlet boxes, conduit and wiring from the panelboard in this area with its 25-foot mounting height. It is a reasonable estimate that can vary either way. Add $50 to each column on the assumption that each luminaire is individually located. The mercury system, column 2, is now 70 per cent instead of 58 per cent, and the incandescent, column 3, is 45 per cent instead of 21 per cent.

Furthermore, in a system which can be installed and wired by more than one well-known and commonly used method, the method selected in the analysis will be indicated by showing the item of Wiring Cost per Luminaire.

In this analysis, if the fluorescent system, column 1, is installed in continuous rows, one outlet would serve as a service entrance for a maximum of nine luminaires on a 15-ampere circuit. At $50 per outlet, the Wiring Cost per Luminaire would be about $5.50, plus about $1.50 per luminaire for pulling and splicing wires throughout the row. For such a continuous row assembly, therefore, add $7.00 for wiring per luminaire to column 1, and add $50.00 per outlet for wiring per luminaire to column 2 and you will find that, in Total Initial Cost, the mercury system is practically equal to the fluorescent instead of 58 per cent of it.

E. H. RADDIN*: The authors have presented an interesting analysis of lighting costs with sufficient refinements to cover most conditions encountered in service. There are some points in this presentation which merit discussion.

On Item 3 of Section A, they suggest that the use of manufacturers' published average wattage for fluorescent lamps be used rather than the nominal watts by which the public has identified fluorescent lamps since the time they first appeared on the market. I am inclined to disagree with this recommendation, in view of the confusion which would result and the inherent characteristics and tolerances which apply to fluorescent lamps and ballasts. For instance, the latest Federal Specifications for fluorescent lamps permit watts 5 per cent above rated, and the latest Federal Specifications for lamp ballasts permit a variation of plus and minus 7½ per cent in watts. These tolerances are much larger than the difference in Table I between "average watts per lamp" and the nominal lamp watts.

In view of this, as well as the change in watts which will occur due to variation in line voltage and the variable ambient temperature, it seems more practical to use the familiar nominal values of lamp watts for such things as lighting cost analysis.

We should bear in mind that the "average watts per lamp" used in Table I for the 400-watt mercury vapor and the 1000-watt incandescent lamp are nominal watts. Federal Specification watt tolerance for the 1000-watt incandescent lamp is 3 per cent, plus or minus.

When we consider all these variables, it seems unwise to confuse the customer and the lighting industry with the use of any rating other than nominal watts for fluorescent lamps.

If the average watts of fluorescent lamps actually deviate from nominal watts by more than a reasonable tolerance, the lamp and ballast manufacturers should get together and design their products to produce nominal watts.

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The authors use the terms "mean lamp output" and "mean depreciation due to dirt collection on lamps and fixtures" in their analysis. This is an encouraging sign and one with which we heartily agree, because it simplifies maintenance and light cost analysis to the point where consumers need not deal with values which vary exponentially. Our own extensive studies have been based on this same thinking.

GEORGE J. TAYLOR*: The need for standardization or following some specific procedure in computing lighting cost analysis has long been felt. Computing lighting costs at random very often leads to false conclusions and misrepresentation of the facts. In reviewing many lighting cost comparisons I have come to fully appreciate the old adage that — Figures never lie but liars can figure (no reflection on the authors of this paper).

Barr and Amick must have been gravely serious when they stated in their opening paragraphs: "Of course, cost comparisons exclude considerations of relative lighting quality which is of equal importance to quantity. Reports showing favorable economy for a lighting system which fails to provide comparable comfort should be accompanied by suitable explanations." Somehow the statement lacks suitable emphasis as written, when in fact it is the most important qualification of any cost study made. Assuming that appropriate lighting levels are provided the value of comfort of seeing (quality) is not merely of equal importance but many times more important than quantity. Let us never lose sight of that. Moreover, what is there to explain about a lighting system which may be economical but not comfortable? Nothing. If it is not comfortable it should not be installed regardless of cost. We are not serious enough about the true significance of comfortable lighting as a profession and that is bad. No wonder we have so many poor lighting installations and so few good ones. My remarks in no way offer a challenge to the authors' statements but are made as an extra precaution to readers. When some day we learn to evaluate comfort of lighting, then we can incorporate this in such tables as proposed by the authors, changing the title perhaps to "Lighting Analysis" which would then include comfort as well as cost.

Under the title "Cost Analysis Objectives," Point 1 it is stated that: ". . . all costs should be equated to an equal maintained footcandles basis." Obviously, we must consider this in our computations. Yet, it must be realized that this is a theoretical consideration and not practical. For example, in studies we made comparing several lighting systems for offices we found it necessary first to make practical lighting layouts for various size rooms. Then an adjustment was made for equal footcandles. One typical example of comparing two systems is of interest in this connection. In a room 40′ x 60′ the following conditions prevailed:

Practical Comparison

	System A	System B
No. of Fixtures	32	70
Calculated Footcandles	49.9	52.5
First Cost	$1958.91	$2167.44
Percentage	100%	110.7%

Theoretical Comparison

No. of Fixtures	32.06	66.64
Adjusted Footcandles	50	50
First Cost	$1962.83	$2063.40
Percentage	100%	105.0%

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If it was decided to *install* System B, the cost over System A would be some 10 per cent greater and not 5 per cent as the theoretical comparison shows. You just cannot throw dollars around like that in today's competitive market.

In the section of "initial cost," Item 10, wiring costs are not included and the reason is appreciated. Nevertheless, our studies show that there may be appreciable differences in wiring costs between fluorescent lighting systems. Wiring costs include cost of installing, panel boards, branch circuits, wiring in conduit (or equivalent), ceiling outlets and local switches. Modern lighting installations consider module layouts especially in offices for flexibility of control. In modern office design at least one switch per module allows for changes in partitions at any time. Based on this, we have found for a room 40′ x 60′ some interesting cost data as related to wiring.

	4 40-Watt louvered fixtures	2 40-Watt louvered fixtures	2 40-Watt luminous indirect fixtures	2 40-Watt aluminum troffers
Wiring Cost	$1427.00	$1182.00	$1328.00	$1212.00

This indicates that there can be as much as a 20 per cent difference in wiring costs between fluorescent office lighting systems.

We have also found that the wiring costs run as high as 20 per cent of the overall cost of many office lighting systems. Unless wiring cost is added to the analysis a true total cost of a lighting system is not presented. It is suggested, therefore, that an item be added to Table I titled "Building Wiring Cost."

We most certainly need a uniform method of presenting cost analyses of lighting systems as suggested by this paper. Owners, architects, engineers and all of us in the lighting industry would benefit because it would result in agreed conclusions. The authors have presented a splendid three-page *outline* on this important subject. Now let them write a 10-page paper including "Building Wiring Costs" and give a complete explanation of all vital items for the sake of clarity and understanding by all. A comprehensive paper on the subject would be a most valuable contribution to our industry.

A. C. BARR and C. L. AMICK*: It is gratifying that the discussors echo the need for greater uniformity in methods of analyzing lighting costs, even though a single typical example cannot, in its details, reflect actual costs for the wide range encountered in practice. This is particularly true of wiring, as several of the discussors emphasize. Hence our warning against assuming a figure instead of ascertaining values applicable to the particular installation.

Mr. Raddin expresses concern over our realistic use of average instead of nominal wattage of fluorescent lamps. This is simply recognition of the facts of an advancing art; any other course would be misleading. The facts of fluorescent lamp wattage are not readily altered, being subject to the characteristics of the operating auxiliaries on which the improved sources are necessarily used.

The present paper, as already stated, deals with only one of the factors in a lighting system. The comments on the importance of lighting quality, though not directly pertinent to our subject, are none the less praise-worthy.

*Authors.