TRANSACTION IES

Accurate Maintenance Factors

By Francis Clark

MAINTENANCE factor is a major expense item in laying out a lighting system; it is a measure of the expense required to operate the system. Low factors may cause the installation of more lighting than is required to meet planned initial levels; the use of high factors can result in less light than desired. With consideration of the maintenance factor must go consideration of maintenance itself: cleaning and relamping the lighting system. Maintenance factor must be recognized for accurate design and performance prediction of an installation. Correct prediction of performance results requires a knowledge of the type of maintenance program to be performed. At least it must be stated that the predicted results are based on the assumption that a specified program will be performed.

Recommended levels of illumination have been greatly increased in recent years. More and more installations are being designed to provide these levels. Changes in manufacture of lamps and equipment must lead to changes in considerations of maintenance, with improvement in quality and quantity of light output always the goal. Change in design of luminaires may increase or reduce surface areas for dirt accumulation. Lamps, in offering higher lumen output, may change their patterns of lumen depreciation, or mortality, or energy consumption. Dollar costs of manufacture, installation, and maintenance seem to increase constantly.

Accuracy in planning grows increasingly important, with each lighting unit costing more, and more units involved. Deviation which might have been of little significance years ago can represent sizable, needless expenditure now—both initially and during the use of the installation. It can also result in marked under-illumination. Probably, there is little danger in having more light than is required, assuming it is properly controlled. Practical economics dictates, however, that once the proper level is established, it should be provided without undue expense.

The present order of procedure in lighting design seems to be to (1) establish illumination levels, (2) choose the luminaire to be used, then (3) calculate the actual size of the installation, using the reducing factors of utilization and maintenance.

It is suggested that the following sequence is a more practical, realistic one:

(1) Determine the quality and quantity of illumination desired.

(2) Consider deterioration from atmosphere and dirt and choose the luminaire best suited to resist or minimize these conditions; consider deterioration from lamp operation and chose lamp type best suited to hours per start, total burning hours, etc.

(3) Choose a cleaning/relamping program fitted to these deteriorating conditions and, assuming it will be performed, establish a maintenance factor which recognizes all these elements.

(4) Elect specific equipment and a specific lamp from the general type already chosen.

(5) Calculate luminaire quantity by the usual formula, with present coefficient of utilization, but using the very specific maintenance factor suggested here.

To achieve greater accuracy in the maintenance factor itself requires analysis and refinement of its components. These are: depreciation of lamps from use, depreciation of luminaires from accumulation of dirt, and change in surroundings from age and dirt. All lamps have the common characteristics of decreasing output, as the light generating elements are being consumed, and failure, when these elements are exhausted. "Depreciation of lamps from use" can be made accurate only by including the time when something will be done to the lamps along with the deteriorating characteristics of the lamps themselves.

For this discussion, fluorescent lamps have been chosen, principally because of their widespread use; their interest is consequently greater. However, this

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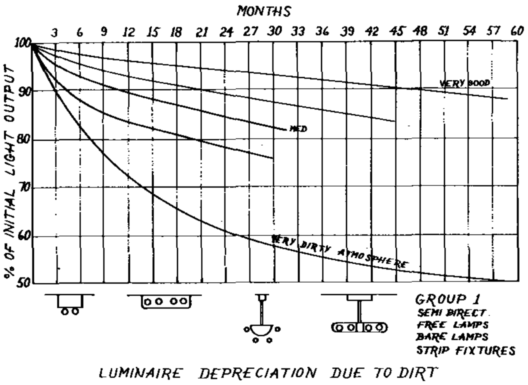
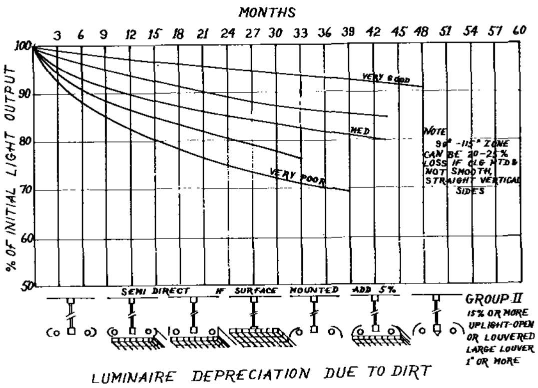


Figure 1.



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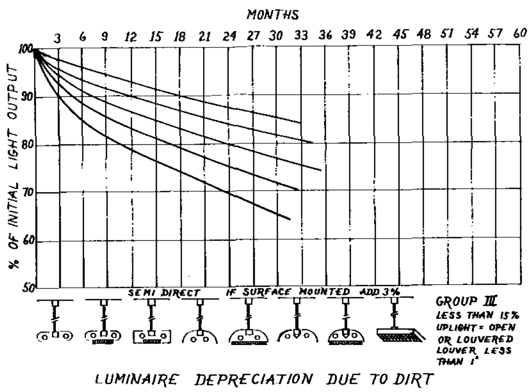

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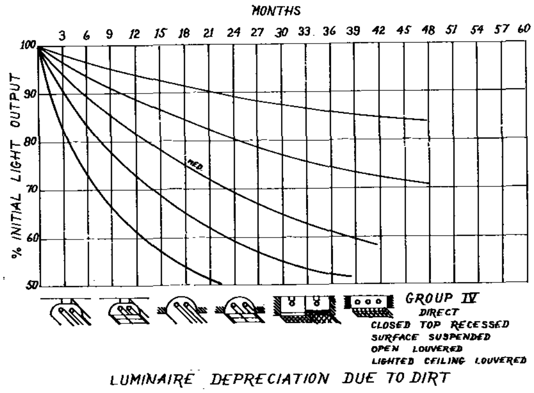


Figure 4.

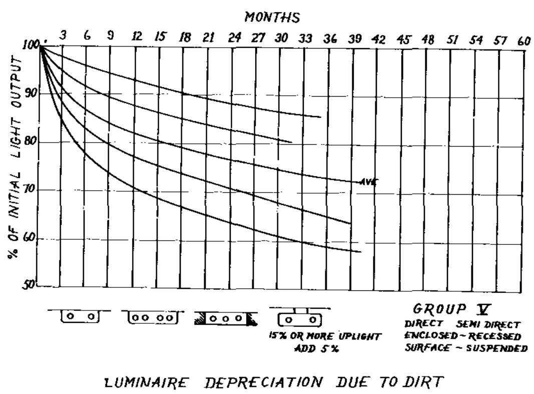


Figure 5.

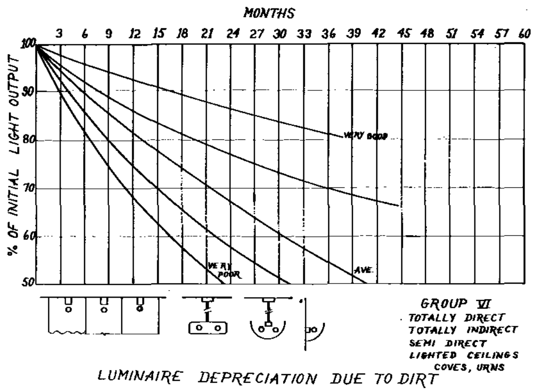


Figure 6.

Figures 1 to 6. Each of the above curves represents luminaire types having similar rates of depreciation from dirt accumulation. Each descending curve represents the average of a group's performance in one of five atmosphere classes.

does not mean that the characteristics of other lamps should escape similar consideration in planning their use. Incandescent lamps, from the layman's view, seem in a more stable state of development. Having been produced for so long, their characteristics seem well established and, in fact, most types do perform in quite similar patterns, when properly positioned and protected. The designer must remember that this lamp reacts markedly to changes in operating voltage. There can be considerable modification in light output, length of life, and use of electricity. Moreover, noting, for instance, how the addition of iodine has improved lumen maintenance, one must recognize the need to be alert to changes in this type as well. The mercury group is closely akin to fluorescent and has much the same pattern of deteriorating characteristics. Here, too, one must be informed of change to be accurate in predicting performance.

Fluorescent lamps seem to have certain characteristics in common. The designer should consider each of the following, in relation to its importance in a given application:

(1). Increasing the average hours burned per lamp start will increase the rated average life and will lengthen the period before burnouts begin.

(2). Lumen output diminishes as total hours of use increase.

(3). Increasing the arc-watts per square inch of phosphor tends to increase the speed of lumen depreciation. With these "higher loaded lamps," increasing the hours per start does not improve rated average life as much, proportionately, as with the earlier type "light loaded" lamps.

(4). Variations from design voltages and optimum ambient temperatures are tolerated over a wide range but, beyond these tolerances, such variations, either high or low, tend to decrease both rated average life and lumen output.

To be valuable, the component "depreciation of luminaires from accumulation of dirt" must include all of the following factors, at least: (1) the type of luminaire; (2) the general conditions of atmosphere and of dirt within the area under study (a room, a building, etc.); (3) the conditions of atmosphere and of dirt outside the specific area and the amount of such atmosphere and dirt that is expected to enter the area and to affect the luminaires.

For this discussion, luminaires have been placed in six general groupings (illustrated in Figs. 1 through 6). Allocation to each group is based on similarity of dirt attracting or retaining construction.

Atmosphere, both inside and outside, contains contamination which may be called "inherent" if it exists almost constantly. Sand from the surrounding soil and humidity from a nearby river are in this category, outside; the inside category includes carbon from tobacco smoke or furnace and lint from rugs, clothing, and draperies. Intermittent contamination, inside, can be considered as "generated," usually from work—wood chips, sawdust, oil vapors from screw machines, etc. Outside, such intermittent contamination might be thought of as "transient" and comes from exhausts of internal combustion engines, irregular operation of a gravel pit or an asphalt plant, etc.

The transmission factor of a building must be considered as well as the characteristics of its interior. Some older buildings will permit ready entrance of outside atmosphere, making this a greater consideration than otherwise. Many new buildings successfully bar passage of outside atmosphere and have facilities to remove much of the dirt from the atmosphere indoors.

When dirt is partly translucent, the depth to which it accumulates is an important factor in light loss. When dirt is opaque and the transmitting or reflecting area has been substantially covered, the volume and rate of dirt accumulation cease to be factors of great importance. Light-colored dirt may have little effect on the depreciation pattern of reflecting surfaces. If dirt is especially adhesive, its accumulation will probably be more rapid, and the resulting depreciation will be greater than in the case of other dirt which is just as opaque yet so dry that it will not stick to luminaire components but simply lie on the horizontal surfaces. Time is an important consideration here, just as in the "depreciation of lamps." It can be measured in days or hours for inherent atmospheres since this depreciation is constant. For transient or generated dirt, it must be measured in specified periods related to the intermittent presence of this contamination.

Reference to Fig. 2, as an example, shows the importance of considering this "dirt component" of maintenance factor and indicates why its refinement seems so necessary. The "very good" condition is in clean atmospheres, inside and outside: say, an air-conditioned office with practically no dirt. "Very poor" is an area of dusty exterior atmosphere and an interior with dark, somewhat adhesive dirt. The best condition represents a depreciation of seven per cent in three years; the worst, 30 per cent. The style of this fitting is, relatively, one of the most dirt resistant, yet this variation is far more than the presently used maintenance factors seem to consider.

"Change in surroundings from age and dirt" is the component of least weight but it does affect the amount of light available. Studies are in process to classify factors in this area also. Completion should yield the basis for a three-part maintenance factor such as is being discussed. Meanwhile, some consideration must be given to it, perhaps by a slight change (in the right direction) of lumen or dirt depreciation figures. It should be remembered that this factor is not necessarily adverse. Fading paint may improve in reflectance; light-colored dirt can obscure a background of lower reflectance.

The present general practice in formulating maintenance factors seems to use a lumen depreciation element which is essentially the same for all lamps. At the same percentage of rated average life for each lamp, regardless of hours actually burned, the lumen output, as a percentage of initial, is taken as lumen depreciation factor. This will make no allowance for the varying times at which a lamp may actually be removed from service. It does not relate lumen output to the increase in rated average life resulting from increased "hours per start." A dirt depreciation component is usually reached even less specifically. The present result is of merit in that it recognizes the need, but it appears to be worthy of greater accuracy.

For this paper, portions of a set of tables and graphs have been selected to illustrate a method of

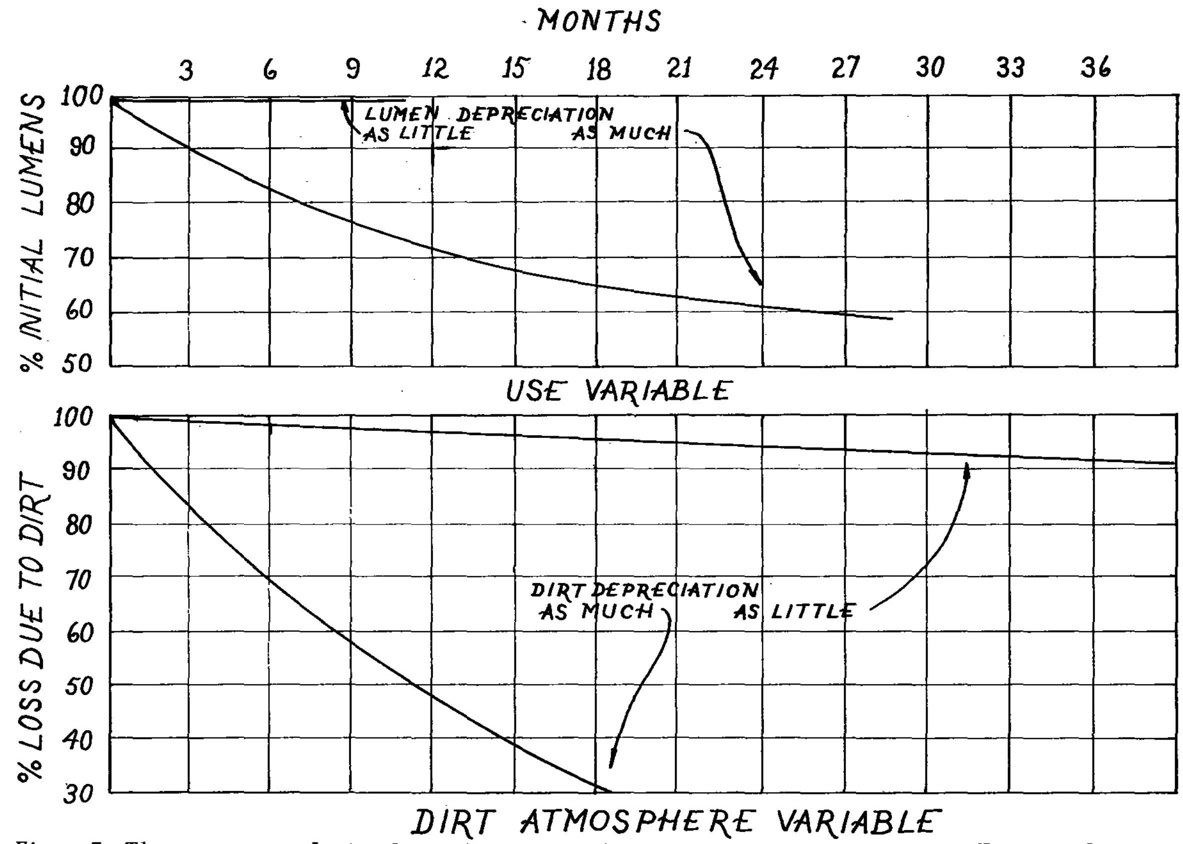


Figure 7. These curves emphasize that wide variations in the components of Maintenance Factor make accuracy necessary in their selection. Upper curve: lumen depreciation of (1) quartz-iodine lamp, and (2) highly loaded fluorescent lamp. Lower curve: dirt depreciation of (1) "low dirt retention" luminaire in very clean atmosphere, and (2) "high retention" luminaire in very dirty atmosphere.

arriving at — and using — a somewhat refined maintenance factor. Fig. 8 depicts the mortality curve and expected burnout pattern of a "lightly loaded" lamp group. It shows change in rated average life, based on changing "hours per start," and the changing points at which burnouts will begin. It provides a reference to lumen maintenance in relation to elapsed burning hours. All this is simply an accumulation, in a condensed form, of information readily available from lamp manufacturers. It must be revised with any appreciable change in lamp performance; it can be prepared for any lamp type about which all the necessary facts are available. Fig. 2 is used to determine the effects of dirt accumulation. Any other of the group, Figs. 1 through 6, would serve equally well as an example. The designer can use somewhat the following procedure:

(1). Having determined the atmosphere and dirt conditions in which the installation will function, compare the performance of all luminaire groups under these conditions and select the group which is least affected by them.

(2). Considering the job requirements, select from this group the specific luminaire best suited.

(3). Having determined the lamp best fitted to the application, in part by comparing other graphs similar to Fig. 8, see what factors are important to the job—time of beginning of burnouts, percentage of depreciation.

(4). Determine when lamps must be replaced to meet these limitations; from the requirements of the job, determine what dirt depreciation is allowable.

(5). Match these relamping and cleaning requirements to create a cycle which most nearly fits both.

(6). On Fig. 2 pick the curve matching the atmosphere and dirt conditions and follow it to the time of cleaning (in months). This point is the Dirt Depreciation Factor.

(7). On Fig. 8, pick the point (in hours) at which relamping will occur. The figure below is the Lumen Depreciation Factor.

(8). For ease, Table I is used to find net Maintenance Factor, which is equal to Dirt $\times$ Lumen Depreciation Factors.

It is important that discretion be used in planning the maintenance program, to arrange that relamping will be done just before burnouts reach the forbidden point and lumen depreciation just reaches the allowable minimum, so that cleaning will occur as dirt approaches the uneconomical stage. Without such care in planning, the whole usefulness of our accurate maintenance factor is negated. Fig. 7 serves as a quick reminder of the danger in using very general maintenance factors. To be noted is the wide variation in results of aging for different lamps. One, depreciating little in lumen output, has the disadvantage of a 2000-hour rated average life. Another, which will operate four or five times as long, will depreciate to 60 per cent of initial output or below. In the lower chart it will be noted that a luminaire which attracts and retains dirt can, when operated in a very dirty atmosphere, depreciate to 30 per cent of its clean state. Yet a luminaire of opposite characteristics in a very clean atmosphere may not reach even five per cent in a similar period of time. Failure to recognize these wide differences can cause "over-fixturing" a job or "under-lighting" it, depending on the way calculations are made.

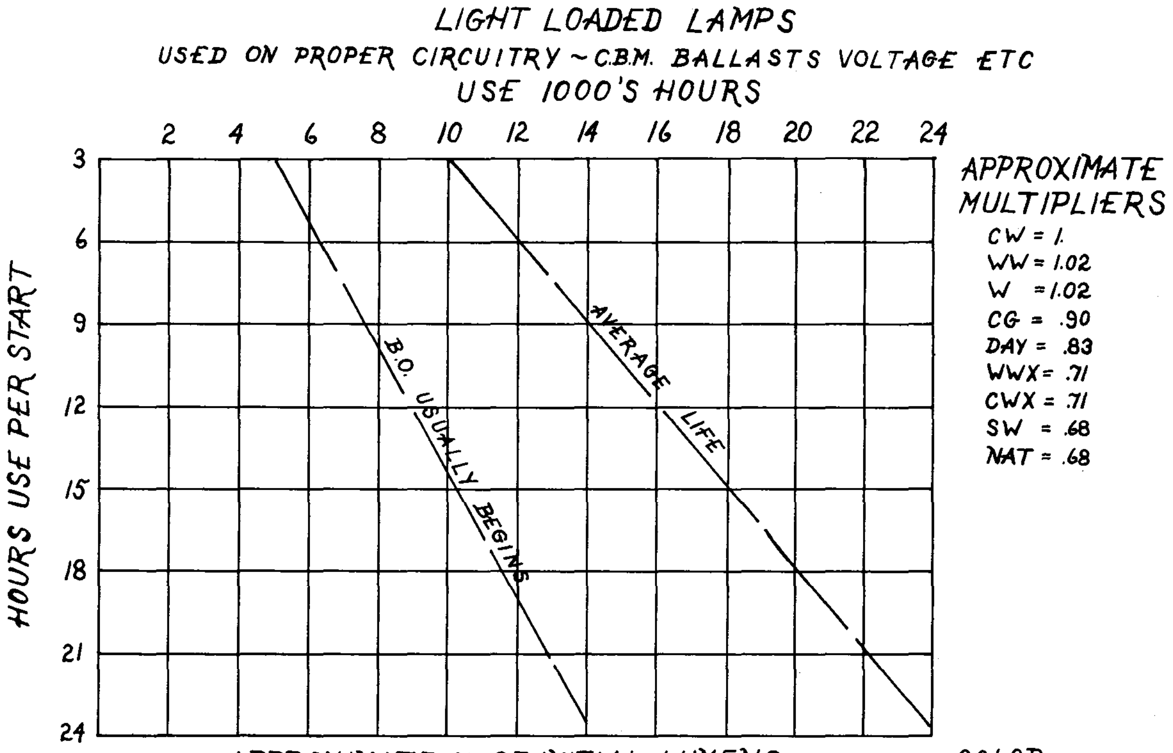
How, reasonably, to decide on accurate cleaning and relamping cycles could well be a subject for a separate paper. It is too involved to elaborate at this time. Bear in mind, though, that the cost per kilowatt-hour of energy, as well as the cost of lamps, maintenance labor, etc., must carry some weight in this decision. As a rule of thumb, it is adequate to assume that for really critical requirements, design and maintenance planning should be calculated to an allowable minimum value at the task (the average being higher, of course). For noncritical calculations, an average value, both for the lighting level and for the physical area, will suffice (the allowable minimum, of course, being lower). In any event, for the sake of comparison, the same criterion must prevail. Without going into detail, a comparison of the proposed and regular approach will be made for two hypothetical cases. In each, assume the same luminaire, one of the group shown in Fig. 2 with lightly loaded lamps, operating ten hours a day from one start, five days a week:

(1). The dirt conditions are considered to be those represented by the top curve (Fig. 2); the program, to clean and 100 per cent relamp every 24 months (5200 hours).

(a) Follow curve to 24 months and see Dirt Depreciation Factor 0.95;

(b) On Fig. 8, follow hours use to 5200 and see Lumen Depreciation Factor 0.85;

Multiply these, or use Table I, and arrive at the Maintenance Factor 0.80. Present practice calls these maintenance conditions "Good"—"Work clean, air free from fumes and dust, lamps to be replaced systematically—Maintenance Factor 0.75." This differ-



APPROXIMATE % OF INITIAL LUMENS												COLOR
91	86	84	82	80	78	76	74	72	70	68	66	CW ~ WW ~ W
85	78	75	72	69	65	63	60	57	55	53	50	DAY ~ CG
87	81	78	75	73	70	67	64	62	60	57	55	WWX ~ CWX
82	75	71	68	64	61	59	56	53	50	47	45	SW ~ NAT

Figure 8. Consolidated information on lumen depreciation, rated average life, and burnout rate for a specific lamp group. This chart may be used for easy selection of accurate lamp data for calculating a more accurate Maintenance Factor.

Table I—Lamp aging data combined with luminaire-dirt depreciation data for quick selection of a more accurate Maintenance Factor. Maintenance Factor = Dirt (Per cent) × Lumen (Per Cent)

Dirt in Atmosphere (Per Cent)	Lumen (Per Cent) 96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58
98	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66	64	62	61	59	57
96	92	90	88	86	84	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56
94	90	88	86	85	83	81	79	77	75	73	71	70	68	66	64	62	60	58	56	55
92	88	86	85	83	81	79	77	75	74	72	70	68	66	64	63	61	59	57	55	53
90	86	85	83	81	79	77	76	74	72	70	68	67	65	63	61	59	58	56	54	52
88	84	83	81	79	77	76	74	72	70	69	67	65	63	62	60	58	56	55	53	51
86	83	81	79	77	76	74	72	71	69	67	65	64	62	60	58	57	55	53	52	50
84	81	79	77	76	74	72	71	69	67	66	64	62	60	59	57	55	54	52	50	49
82	79	77	75	74	73	71	69	67	66	64	62	61	59	57	56	54	52	51	49	48
80	77	75	74	72	70	69	67	66	64	62	61	59	58	56	54	53	51	50	48	46
78	75	73	72	70	60	67	66	64	62	61	59	58	56	55	53	51	50	48	47	45
76	73	71	70	68	67	65	64	62	61	59	58	56	55	53	52	50	49	47	46	44
74	71	70	68	67	65	64	62	61	59	58	56	55	53	52	50	49	47	46	44	43
72	69	68	66	65	63	62	60	59	58	56	55	53	52	50	49	48	46	45	43	42
70	67	66	64	63	62	60	59	57	56	55	53	52	50	49	48	46	45	43	42	41
68	65	64	63	61	60	58	57	56	54	53	52	50	49	48	46	45	44	42	41	39
66	63	62	61	59	58	57	55	54	53	51	50	49	48	46	45	44	42	41	40	38
64	61	60	59	58	56	55	54	52	51	50	49	47	46	45	44	42	41	40	38	37
62	60	58	57	56	55	53	52	51	50	48	47	46	45	43	42	41	40	38	37	36
60	58	56	55	54	53	52	50	49	48	47	46	44	43	42	41	40	38	37	36	35
58	56	55	53	52	51	50	49	48	46	45	44	43	42	41	39	38	37	36	35	34
56	54	53	52	50	49	48	47	46	45	44	43	41	40	39	38	37	35	35	34	32
54	52	51	50	49	48	46	45	44	43	42	41	40	39	38	37	36	35	33	32	31
52	50	49	48	47	46	45	44	43	42	41	40	38	37	36	35	34	33	32	31	30
50	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29
48	46	45	44	43	42	41	40	39	38	37	36	36	35	34	33	32	31	30	29	28

ence, 0.75 to 0.80, is small, something over five per cent, but if the life of the installation is ten years, then the saving in investment and operating cost will go far toward paying for half the installation.

(2). The dirt conditions are considered to be those represented by the lowest curve in Fig. 2; program, clean and 100 per cent relamp every 36 months (7800 hours).

(a) Following the same procedures, 36 months gives a Dirt Depreciation Factor of 0.70; 7800 hours a Lumen Depreciation Factor of 0.82; Maintenance Factor 0.57.

Present practice indicates a classification of "Poor"—"Maintenance Factor 0.65." This assumes lamp replacement only after burnout whereas the example above is group relamped at about 80 per cent of rated average life. Actually, the 0.57 should be lower to account for burnout, instead of group replacement. This difference, 0.65 to 0.57, about 14 per cent, represents the amount by which this job will be underlighted.

These examples are by no means exact, or foolproof, but they must assuredly point up the need for greater accuracy and indicate a way to obtain it.

If these premises are valid, and a greater accuracy is warranted and obtained for maintenance factors, and greater attention is given to maintenance itself, then it is of prime importance for the designer to have at hand accurate and timely information. There must be very reliable performance data for lamps and luminaires—through a broad range of circumstances. The designer must establish the atmospheric and dirt conditions that will prevail and the maintenance program that will be performed. Maintenance people must be alert to any changes in the characteristics of lamps being furnished for replacement and alert to such modifications of environment as changes in room use, paving of a particularly sandy yard, installation of air conditioning, etc. Maintenance factors and programs will then be revised to fit the circumstances and be of continuing accuracy and economy.

DISCUSSION

Arthur A. Brainerd:* A paper such as this is long overdue. It should become an important part of our rapidly accumulating knowledge of the art and science of illumination.

Mr. Clark's charts seem quite authentic, but their origin may not be familiar to many of us. May I suggest the addition of a suitable bibliography? This would enhance the value of these data and be of help to those wishing to pursue the study further.

In dealing with maintenance, as with other forms of light application, we must not overlook the fact that precision and

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accuracy are by no means synonomous. A plus or minus variation of 5 per cent or even 10 per cent could very well be considered accurate, under certain circumstances. For many years we based our depreciation estimates on average illumination values for the life of the lamps, when terminal illumination would have been far more realistic. I think that Mr. Clark has this in mind.

The method described is both logical and effective, although technological changes often necessitate changes in details of application. One thing is certain—when the maintenance problem is approached systematically along these general lines, the net result is, in general, a much higher coefficient of utilization.

John F. Foulkes:* The paper explains how to arrive at accurate maintenance factors and presents graphical data which show *approximate* curves showing the rate of dirt accumulation on various *general* types of luminaires. The paper explains further that this "factor" is made up of three portions, namely, lumen depreciation of the lamp, dirt accumulation on the lamp and luminaire, and dirt accumulation on other surfaces of the room.

Obviously, most lighting designers cannot control or *accurately* predict a rate of dirt accumulation on a wall and its effect on reflectivity. A typical designer may find that his 70 per cent wall has been changed to 15 per cent at the whim of an interior decorator or corporate officer. This same corporate officer may slash $100,000 from the project after seeing bids by eliminating electrostatic filtering from the ventilation system. Will the lighting designer rush back to the drawing board and reconsider maintenance factor? . . . !

If data were available for individual luminaires resulting from actual dirt accumulation tests by impartial testing agencies, a meticulous designer would use this information in *estimating* dirt accumulation on the lamp and luminaire. Such data would also be of value in making comparisons of competitive units.

Lumen depreciation is, in my opinion, the most important portion of the maintenance factor and, fortunately, the easiest to determine accurately since the lamp manufacturers generally will supply lumen depreciation curves.

The "ease of maintenance" for any given luminaire is, in my opinion, of utmost importance in the designer's consideration. He should examine a unit carefully to assure that it is easy to replace lamps and to clean. A luminaire which requires a Houdini to insert or remove lamps is *likely* to result in a very low maintenance factor.

I think the writer did a good job in pointing out the make-up of the maintenance factor and in showing how widely it can vary depending on the *designer's* judgment. I think the most important point to be gained from the paper is that accurate maintenance factors can be assured only if the designer *and* maintainer collaborate during the design stage of a project on the establishment of optimum maintenance intervals.

Morgan Christensen:** The author is to be congratulated on the scope of the investigations into the maintenance characteristics of a wide variety of fluorescent luminaires under the range of field conditions that exist. These data supply much needed information that should be helpful to all segments of the lighting industry.

Designers of lighting systems will be able to choose proper equipment for the environmental conditions that prevail with a great deal more assurance than before.

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**General Electric Co., Nela Park, Cleveland, Ohio.

Users will obtain better lighting systems and will be able to plan maintenance schedules much more realistically.

Equipment designers can also learn much of benefit concerning the characteristics of luminaires which contribute to minimum dirt collection. This should lead to better designs in the future.

It is to be hoped that these data are widely accepted and also further expanded. Does the author have plans to obtain similar data for filament and mercury luminaires?

Leo E. Duval:* As past Chairman of the Maintenance Committee and by his own business associations, the author of this paper is in an excellent position to analyze the problem of selecting the proper maintenance factors for different lighting conditions. Lamp life and lumen maintenance are continuously under study by all lamp manufacturers, and considerable information based on laboratory test conditions is available to accurately determine lamp lumen depreciation and how it contributes to the maintenance factor.

A major effort has been made in this paper to consolidate all of the contributing factors into one composite maintenance factor which has a real basis and is not chosen merely on whether the designer considers the installation will have "good," "medium" or "poor" conditions.

I would like to ask the author if, in Figs. 1 through 6, a control group of lamps was used to determine luminaire depreciation due to dirt, or if manufacturers' lamp lumen depreciation data were used to estimate the dirt depreciation component? Also on these same charts, does the dirt depreciation figure include wall, ceiling and floor reflectance depreciation, or is it strictly luminaire depreciation as stated?

The statement is made in the text that "change in surroundings from age and dirt is the component of least weight." Does the author have field test data to substantiate this statement?

Francis Clark:** General acceptance of this suggested (and I believe more accurate) method of determining maintenance factor by these widely-known gentlemen, is very gratifying and, I hope, indicates that the data are of a sound and useful nature.

The curves were made from footcandle readings taken in several hundred locations in actual field use. The same lamps were always reinstalled in the same luminaire for the "clean" reading. This measured only "dirt" affecting light loss. Three readings were taken before and after each cleaning at locations 18 inches directly below longitudinal center line of unit; one reading in the middle, one at either end—all three at the same point before and after. Readings are averaged each time. Change in surroundings from time and dirt are not usually very significant except in rare cases. If any change in surroundings, surfaces or atmosphere occurs from the planned initial, it can affect the maintenance factor and all calculations should be refigured. An example of this might be a foundry, where dirt gathers rapidly. In this case, the condition, it would seem, should have been observed in the initial evaluation of Dirt Depreciation Factor, and so figured. If painting, air conditioning, type of work performed in the area, filtering, new floors, equipment, furniture, etc., are changed, this could affect the maintenance factor and/or the coefficient of utilization. We do have a little data on this, and on incandescent and fluorescent, but not enough to present as yet.

*Sylvania Electric Products Inc., Salem, Mass.

**Author.

Accurate Maintenance Factors—Part Two (Luminaire Dirt Depreciation)

By Francis Clark

IN 1962 the author outlined the need for accuracy in deriving and using "Maintenance Factor," recognizing that this is the designer's ultimate resource for predicting or expressing the performance of a lighting system. The economy of purchasing and operating such a system can depend on his use of an accurate factor because the amount of light actually delivered, in relation to that designed to be delivered, depends on such accuracy. Along with this design prediction must go the prediction of, and adherence to, a properly planned physical program of maintenance—or the recognition that no program is planned or will be performed.

"Maintenance Factor" is, in essence, the final result of measuring the various reductions in light output stemming from all the causes of light loss. These causes are relatively well known and understood in themselves. It is in recognizing and assessing them that deficiencies occur. Accuracy and completeness in such assessment is important for this represents the effective accuracy in predicting the performance of the lighting system. These causes of light loss are shown graphically in Fig. 1 and are discussed below.

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Ballast Inefficiency and Improper Ambient Temperature and Voltage

These three causes of light loss are shown combined on Fig. 1 for several reasons. All exist in practically every fluorescent lamp installation; and usually all three remain uncorrected, sometimes because such correction is not physically possible, generally because correction is not economically justified. Individually, each cause is responsible for only a small loss, varying from installation to installation; yet the total loss from the combined causes of light loss seems to be somewhat constant from system to system.

(a) The lamp-lumen values published by manufacturers of fluorescent lamps and mercury lamps are based on tests performed in their laboratories using ballasts of extremely high efficiency. This is gained by unusually high standards of design and manufacture and is probably maintained by constant

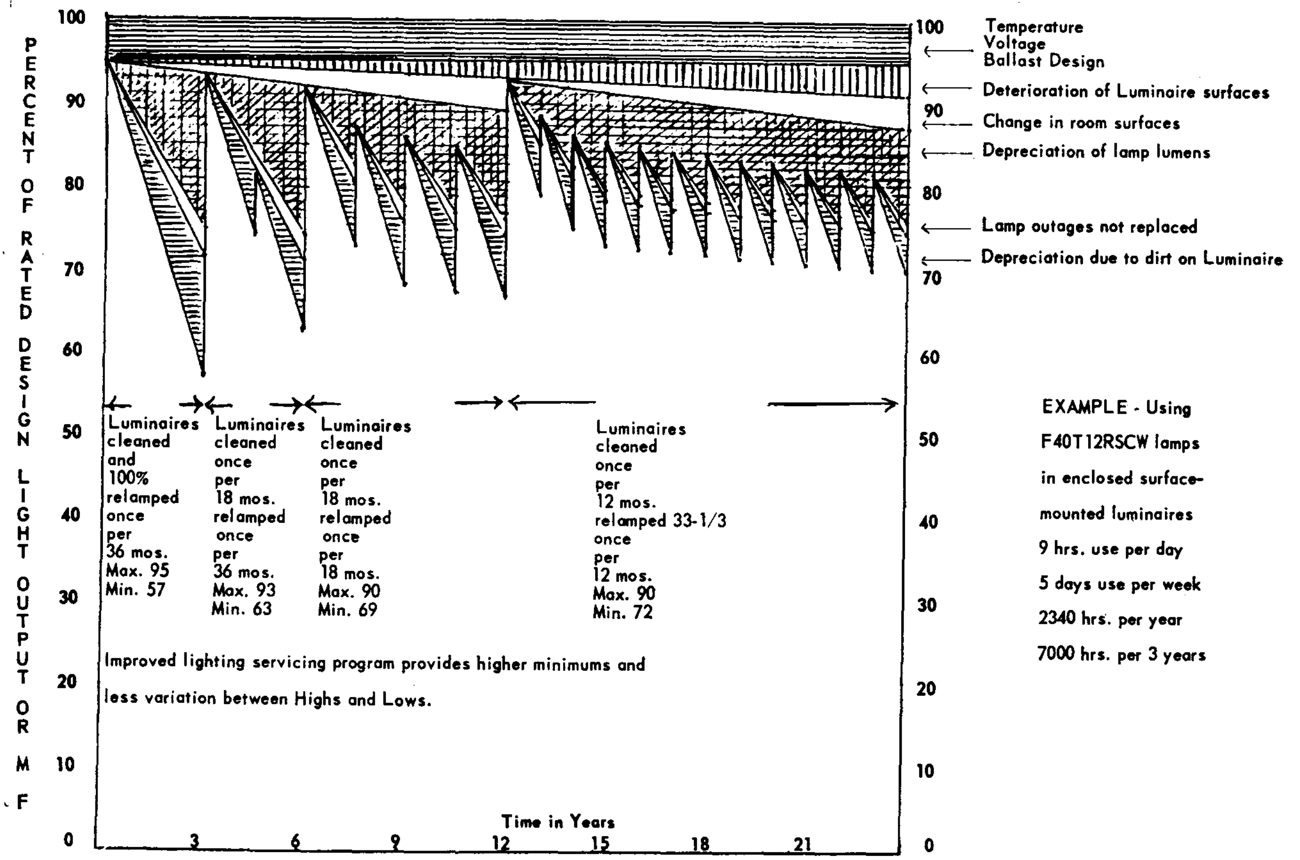


Figure 1. Causes of light loss (cumulative effects).

automatic correction of any remaining deficiencies. Thus the test lamps are operated at their maximum output. In the field, it is not yet economically possible to use ballasts of such performance or corrections of such accuracy, so the designer must apply some reducing factor to the published lamp-lumen values to compensate for this light loss before he proceeds with his calculations. It is the author's opinion that this loss may vary from zero to five per cent depending on ballast quality and application. The designer should ascertain the manufacturer's statement of the performance of the particular product in the particular application.

(b) Improper ambient temperature, high or low, has adverse effects on the lamp directly, on the ballast directly, and, through the adversely affected ballast, on the lamp indirectly.

(c) Improper primary voltage, high or low, has direct adverse effect on incandescent lamps and ranks with improper temperature for its adverse effect on ballasts and for its adverse, indirect effect on fluorescent and mercury lamps through the adversely affected ballast. The manufacturer should be consulted before reaching a final decision on the product to be used. In new installations it is possible to provide adequate ventilation, adequate conductors, etc., to prevent incorrect voltage and temperature. In installations already operating, the cost of corrections may be such that they will never be made and the reduction in light output will remain constant. The author feels the loss resulting from these two causes is between zero and five per cent. All three losses are represented on Fig. 1 as an approximate average constant of five per cent.

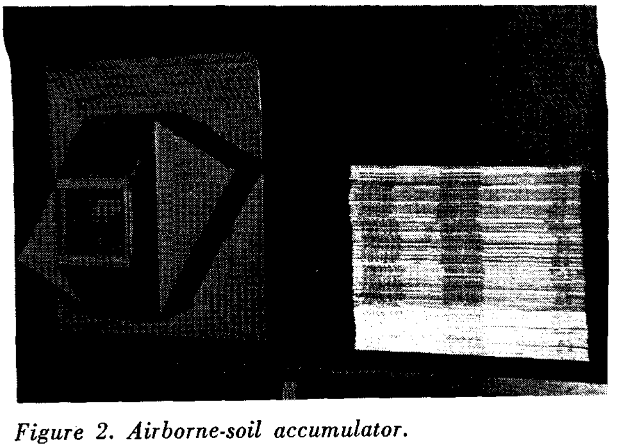


Figure 2. Airborne-soil accumulator.

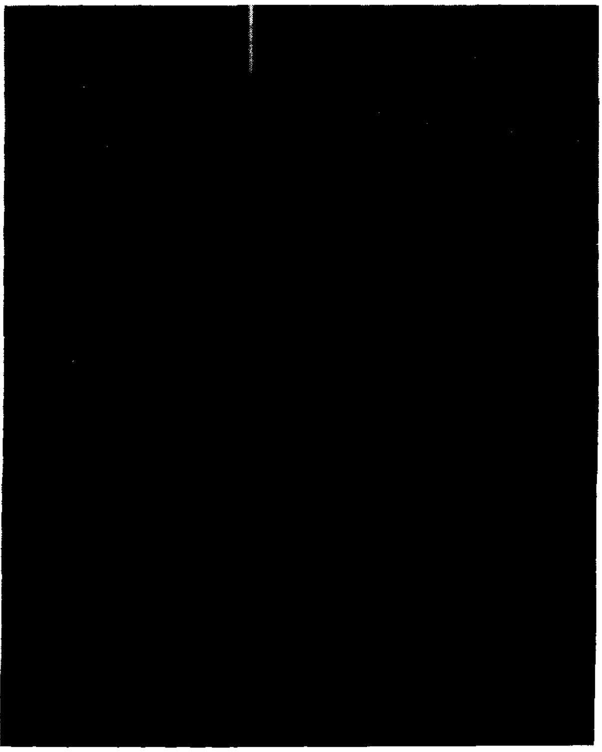


Figure 3a. Accelerated-testing device—exterior.

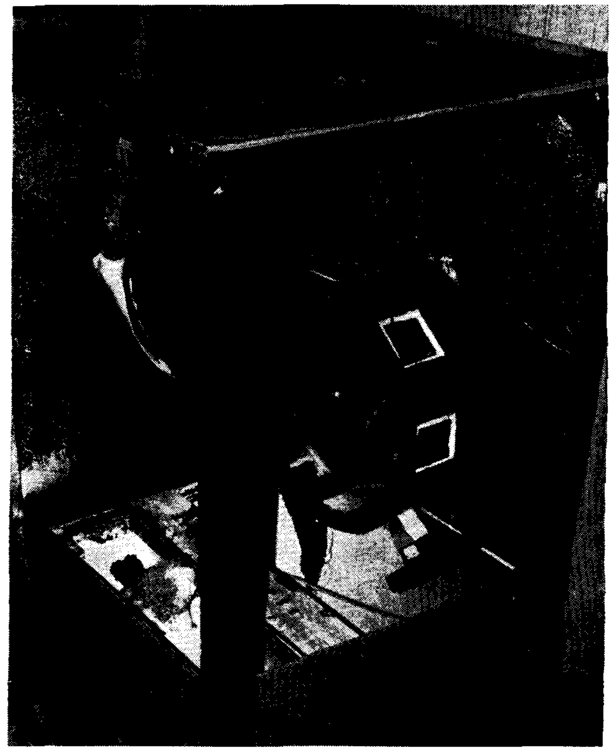


Figure 3b. Accelerated-testing device—interior.

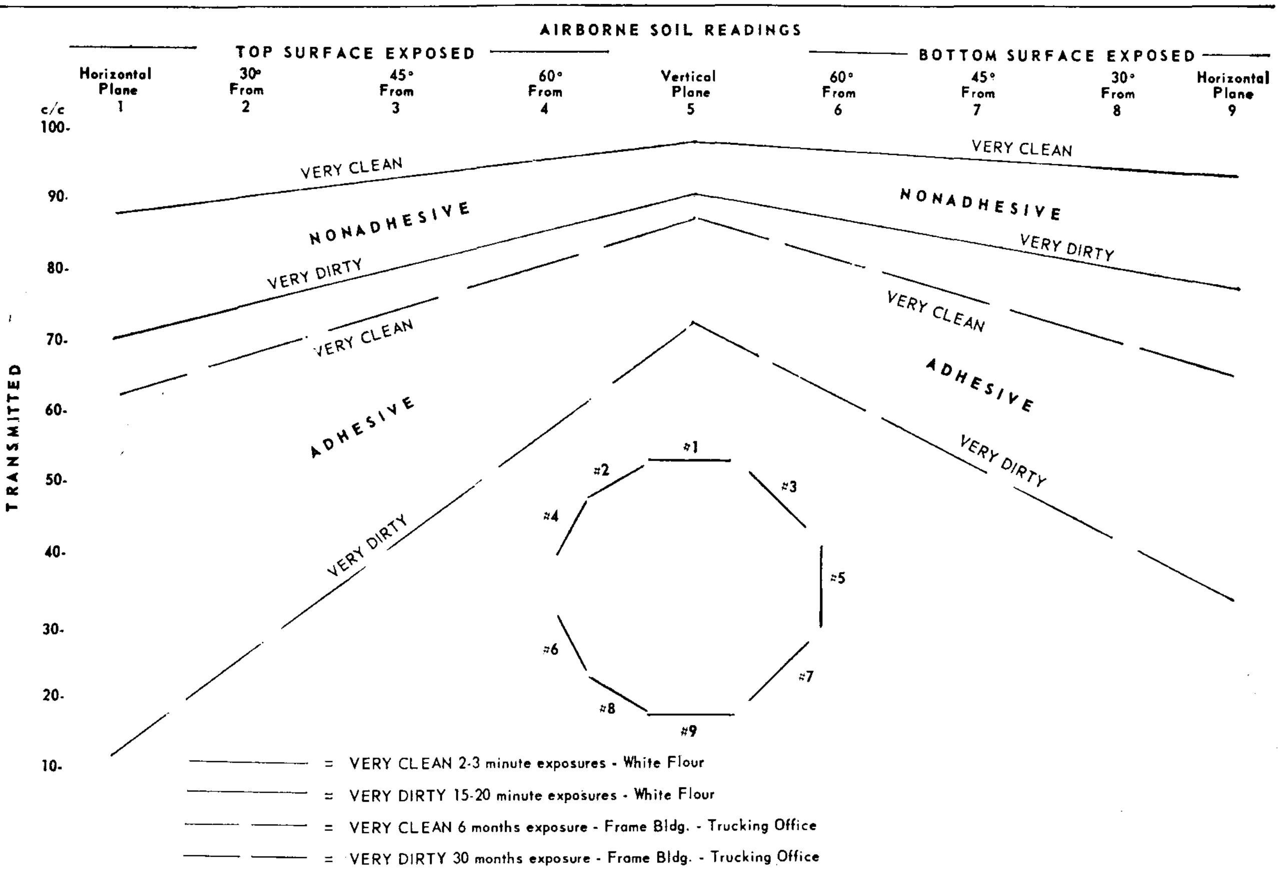


Figure 4. Test-result averages from airborne-soil accumulator and accelerated-testing device.

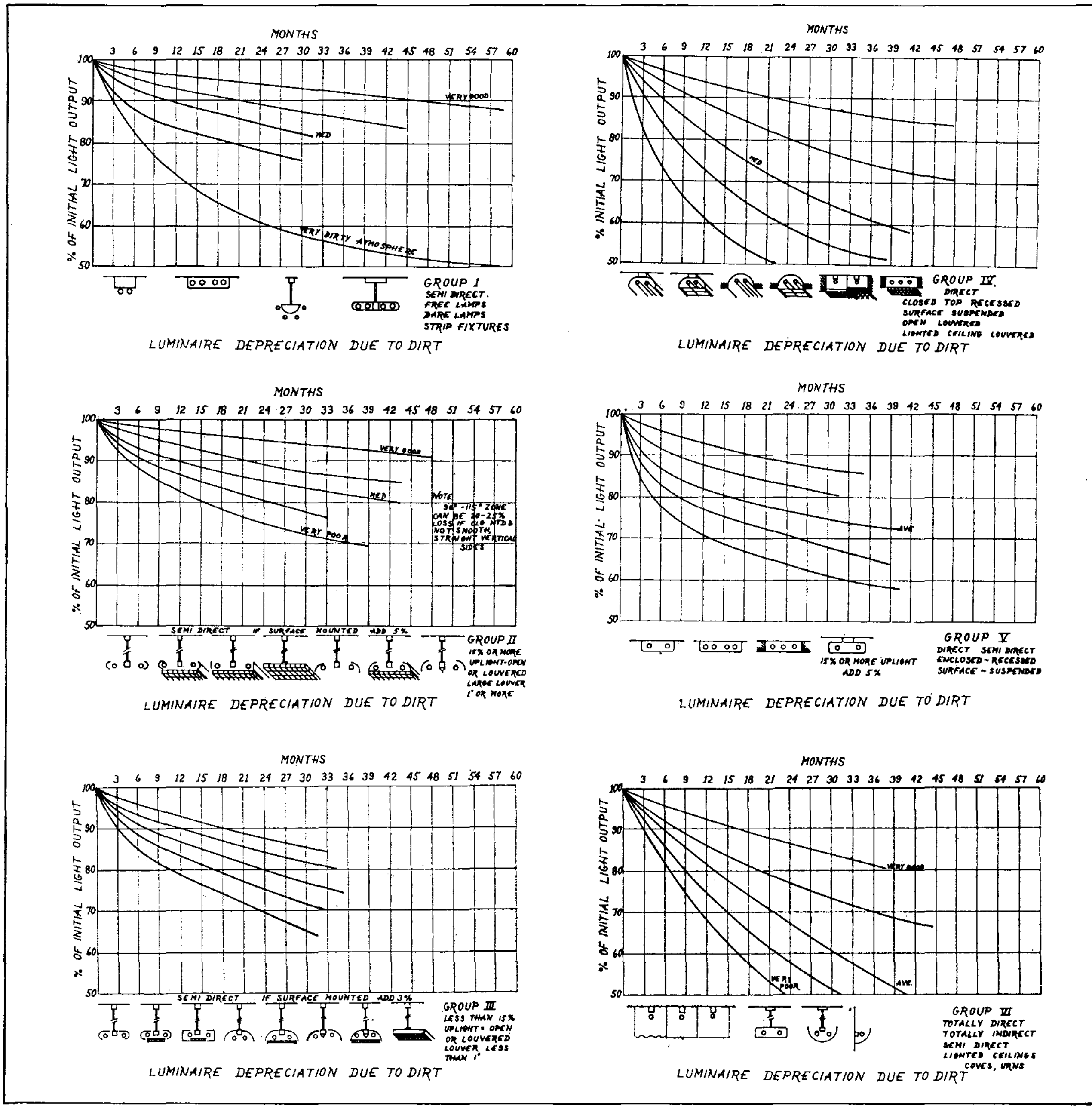


Figure 5. Graphs showing dirt depreciation curves for luminaires grouped according to their similar rates of depreciation.

Luminaire Finish and Material

Loss resulting from this cause is being reduced year by year with the development of increasingly more light-stable and durable plastics for use in shielding media and in metallic finishes. It is likely that the time is not far distant when the proper cleaning of a luminaire actually will restore it to a condition so close to initial that this factor will no longer need to be included. However, most luminaires in present service do still have components that are deteriorating over the years: glass that is porous enough to retain some quantities of light-absorbing dirt; plastic shielding that darkens with continuing exposure to light and so decreases, imperceptibly, in transmission efficiency; painted finishes that darken with time or peel and expose metal parts of an even lower reflection factor than that of the aged paint itself. These causes of loss can be corrected; but as a matter of practice such correction is rarely accomplished. It is true that broken plastic or glass parts will frequently be replaced with new. Sometimes, even badly deteriorated luminaire chassis will be repainted. But the volume of this

FIVE CATEGORIES OF DIRT CONDITIONS					
	VERY CLEAN	CLEAN	MEDIUM	DIRTY	VERY DIRTY
Generated Dirt	None	Very little	Noticeable but not heavy	Accumulates rapidly	Constant accumulation
Ambient Dirt	None (or none enters area)	Some (almost none enters)	Some enters area	Large amount enters area	Almost none excluded
Removal or Filtration	Excellent	Better than average	Poorer than average	Only fans or blowers if any	None
Adhesion	None	Slight	Enough to be visible after some months	High (probably due to oil, humidity or static)	High
Examples	High-grade offices, not near production; laboratories; clean rooms, etc.	Offices in older buildings or near production; light assembly; inspection, etc.	Mill offices; paper processing; light machinery, etc.	Heat treating; high-speed printing; rubber processing, etc.	Similar to DIRTY but luminaires within immediate area of contamination

Figure 6. Five categories of dirt conditions (example of classifying atmosphere and dirt).

sort of restoration is rarely enough to change the pattern of gradual decline shown in Fig. 1.

Accumulation of Dirt on Room Surfaces

This cause of light loss is usually eliminated from time to time by cleaning or painting walls and ceilings, but it is unlikely that this rejuvenation will be accomplished often enough to change the general pattern of loss from that indicated in Fig. 1. In a way, recognition of this loss has been removed from the scope of Maintenance Factor because the present practice is to account for it in the selection of ceiling and wall reflectance values when calculating Luminaire Coefficients of Utilization.

Burned Out, Unreplaced Lamps

With the growing popularity of group relamping programs, this cause of light loss is, generally speaking, being lessened. Also tending to reduce this loss is the improvement in lamp mortality patterns, *i.e.*, more and more lamps in the group burning out nearer and nearer to the point of rated average life, thus producing a steeper mortality curve. However, even the most carefully planned group relamping program will yield burnouts because it is unlikely that economy will ever permit relamping frequently enough to eliminate them entirely. It is up to the designer to obtain from the manufacturer a projected burnout pattern of the lamp under consideration for the particular application, to determine what amount of these burnouts will remain unreplaced between group relampings and then to include in his calculations a factor for the amount of light thus lost in relation to the total output of the system. For illustration, Fig. 1 assigns a value approaching five per cent, but each installation will vary depending on the type of lamp, maintenance planned and performed, etc.

Lamp-Lumen Depreciation

Aging of lamps produces this cause of light loss. Its amount should be accurately determined by reference to manufacturers' statistics for the performance of each particular type. Fortunately there are lumen depreciation graphs and tables available for practically every kind of lamp from most manufacturers. Different phosphors depreciate at differing rates, so the designer must be sure he is considering the information that applies to the particular color of lamp in which he is interested. Proper choice of this value will result in a lamp-lumen-depreciation factor that does accurately measure the relation between the initial output of a new lamp and output of the same lamp at the time of its planned replacement. Accuracy here is doubly important because this loss is one of the two largest ones and because the factor that measures it is one of the two principal components of Maintenance Factor.

Luminaire Dirt Depreciation

The light loss resulting from this cause is one of the two largest and seems to be the most difficult to measure and predict. But it is certainly the easiest

EVALUATION OF OPERATING ATMOSPHERE	
FACTORS FOR USE IN TABLE BELOW	
0 = No dirt—very unusual	3 = Average
1 = Cleanest conditions imaginable	4 = Dirty, but not the dirtiest
2 = Clean, but not the cleanest	5 = Dirtiest conditions imaginable

	ADJACENT ATMOSPHERE						FILTER FACTOR per cent of dirt passed		SURROUNDING ATMOSPHERE						SUB TOTAL
	Inter-mittent		Constant		Total				From adjacent		Intermittent		Constant		
ADHESIVE DIRT Intrinsic		+		=		×		=		+		+		=	
ADHESIVE DIRT Electrostatic		+		=		×		=		+		+		=	
NON-ADHESIVE DIRT		+		=		×		=		+		+		=	
TOTAL OF ADHESIVE- AND NONADHESIVE-DIRT FACTORS															

0—12 Very Clean	12—24 Clean	25—36 Medium	37—48 Dirty	49—60 Very Dirty

Figure 7. Evaluation of operating atmospheres (table for calculating atmosphere—dirt categories).

one to recover because a thorough cleaning of the luminaire will, for the most part, restore it to a condition equaling its initial clean state. Loss of light from each of the other causes is either relatively small or, in the case of lamp-lumen depreciation, readily determined. The problem that arises in the case of luminaire dirt depreciation is that of trying to determine in advance the effects of various atmospheres and various kinds of dirt on various kinds of luminaires.

The author has gathered thousands of readings taken before and after luminaire cleaning in circumstances where the time elapsed between cleanings was known. These constitute useful luminaire-dirt-depreciation figures for every common general type of luminaire in a great variety of atmosphere and dirt conditions. A credible system of classification evolved as these readings were sorted by luminaire group and by atmosphere-dirt conditions. However, the author's goal had been to relate the luminaire-dirt-depreciation factor of a particular luminaire to the sizes, angles and finishes of the various surfaces it presented for the attraction and retention of dirt and relating this, in turn, to the variety of atmospheres and kinds of dirt in which it might operate.

To test along these lines, two nine-plane accumulators were fabricated. The smaller one (see Fig. 2) served as a natural-rate airborne-soil accumulator (ASA). The larger (see Fig. 3) operated as an accelerated-testing device (ATD). ASA was stationary for 30 months, during which time five tests were made. At each test interval light transmission was measured through each half of each glass plane. One half remained dirty for full-term accumulation; the other half was cleaned after each short-term accumulation measurement and remeasured to provide a control for mathematical correction of possible test-light variation. A constant quantity of domestic white flour was blown repeatedly into ATD for varying periods of time in an attempt to simulate the varying rates of dirt accumulation in locations as they vary from "very clean" to "very dirty."

ASA was located in a wood frame office inside an unheated trucking terminal. Room temperature

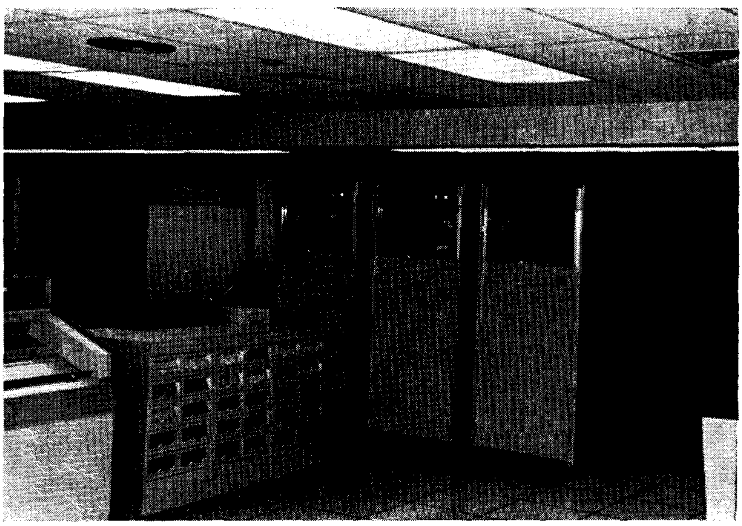
Figure 8. Crowded office open to dirty commercial area—Medium (30).
3 – 4 – 7 – 0 – 7 – 4 – 3 — 14
0 – 0 – 0 – 0 – 0 – 0 – 0 — 0
4 – 4 – 8 – 0 – 8 – 4 – 4 — 16 — 30

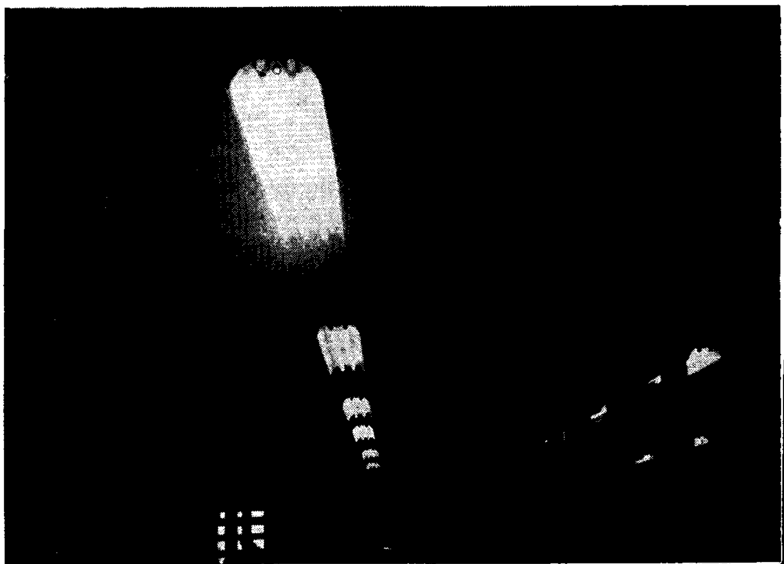
varied from 50 to 95 F and relative humidity from 35 to 75 per cent depending on outdoor conditions and the functioning of unit air conditioners and steam radiators. Oil vapors and exhaust fumes from the trucks and sand and cinders from the unpaved turn-around yard were always present. Dirt generated within the office was, in itself, of the nonadhesive nature to be expected from paper handling by four to six people. However, it became adhesive from contact with oil vapors, humidity, etc. ATD was operated entirely in an atmosphere with temperature hardly varying from 70 F and relative humidity controlled at 45 per cent. The dirt was definitely nonadhesive.

Time and facilities simply were not available to relate this testing directly to the characteristics of luminaire groups. Fig. 4 does, however, illustrate the results in a graphic general way. It does show, for instance, that on the same simulated luminaire plane the measured effect of dirt accumulation can vary from 88 (nonadhesive dirt in a "very clean" atmosphere) to 12 (adhesive dirt in a "very dirty" atmosphere).

From previous studies of atmospheres and dirt categories and from the more detailed knowledge gained by this testing, a rating system has been developed. This seems to satisfy the need for a relatively accurate, although not scientific, method to classify the circumstances facing the lighting designer. In an earlier paper the author presented a grouping of most common luminaires divided into types having similar rates of depreciation from accumulation of dirt. This grouping has met general approval, as have the curves depicting the perform-

Figure 9. Computer room, air conditioned and filtered—Very clean (9).
3 – 3 – 6 – .2 – 1 – 1 – 1 — 3
0 – 0 – 0 – .2 – 0 – 1 – 1 — 2
4 – 4 – 8 – .2 – 2 – 1 – 1 — 4 — 9





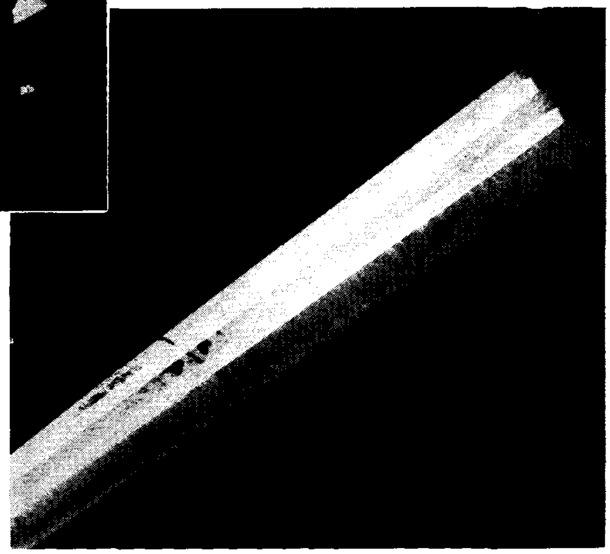


Figure 10. Aluminum plating, open to dirty industrial area—dirty (38). (Above) General view. (Right) Luminaire close-up

4 – 4 – 8 – 0 – 8 – 5 – 5 — 18
1 – 1 – 2 – 0 – 2 – 1 – 1 — 4
4 – 4 – 8 – 0 – 8 – 4 – 4 — 16 — 38

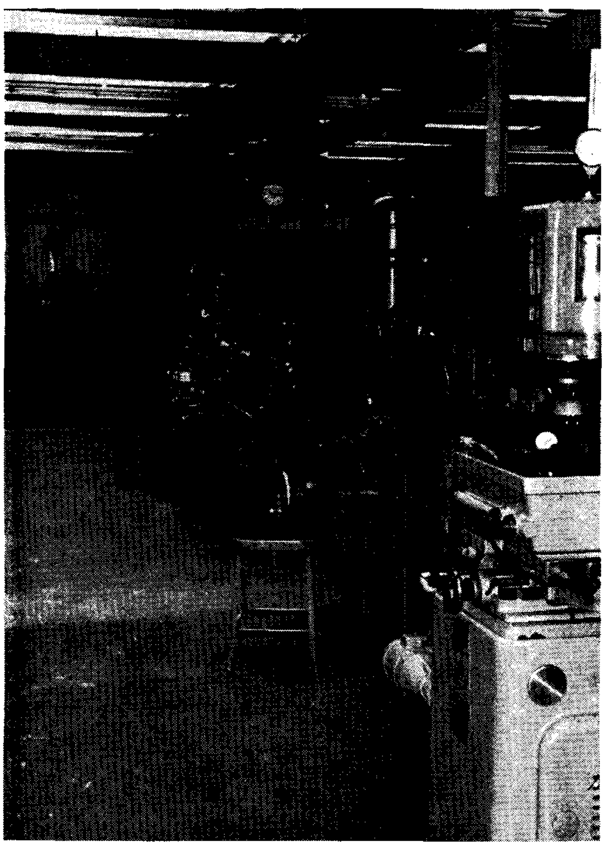
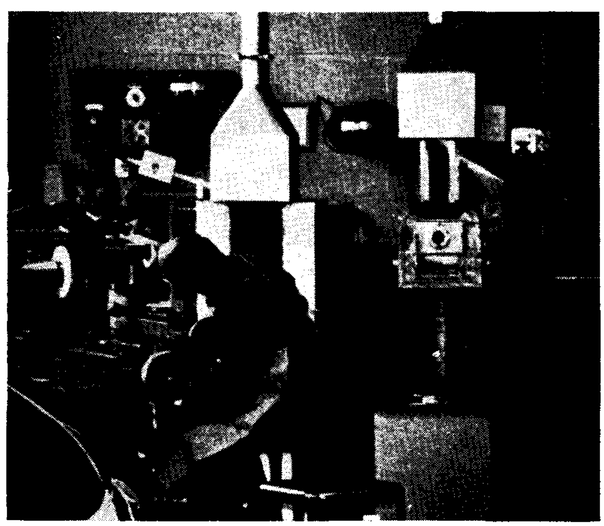


Figure 11. Neat tool and grinding, air conditioned and filtered—very clean (8). (Left) General view. (Below) Close-up.

3 – 2 – 5 – .1 – 1 – 2 – 1 — 4
0 – 0 – 0 – .1 – 0 – 0 – 0 — 0
3 – 3 – 6 – .1 – 1 – 2 – 1 — 4 — 8



ance of each luminaire group in the five atmosphere-dirt categories: "very clean," "clean," "medium," "dirty," and "very dirty." This luminaire grouping is repeated here for reference as Fig. 5.

With these groupings as a guide, and the decision made as to which group represents the luminaire in question, the next step is to determine which one of the atmosphere-dirt curves applies. Fig. 6 is furnished as an ideal set of facts that illustrates how circumstances can combine to lead to that decision. Actually, it is unlikely the designer will find any single column fitting the facts with which he has to contend.

The chart, Fig. 7, "Evaluation of Operating Atmosphere," is intended to be an almost self-sufficient form that can be completed to arrive at the desired decision. The factors "0" to "5" should be noted and inserted in the spaces as they are required to describe the conditions of the problem. The column "Adjacent Atmosphere" is intended to represent that in the area separated from, but next to, the area in which the luminaire itself operates (this latter being the "Surrounding Atmosphere"). The "Filter Factor" represents the percentages of dirt allowed to pass through the division between "Adjacent Atmosphere" and "Surrounding Atmosphere;" the column "From Adjacent" indicates the net amount of such dirt that did pass through. This division can, of course, be an open window, with a filter factor of zero, or an air-conditioning system with a factor of 99 per cent. After arriving at the total of all factors, the resulting value can be translated into the applicable atmosphere-dirt category by reference to the bottom line of the chart.

To review the total recommended procedure: (1) Determine the atmosphere-dirt category from Fig. 7; (2) choose the correct luminaire-group graph from Fig. 5; (3) on this graph, locate the applicable dirt-depreciation curve; (4) on this graph, locate the appropriate elapsed-time-between-cleanings point; and (5) read the Luminaire Dirt Depreciation Factor at the crossing-point of (3) and (4) above.

Six photographs (Figs. 8 through 11) are included as a further assistance in becoming accustomed to the use of Fig. 7. Their captions give a brief description of the circumstances, state the author's classification of the atmosphere-dirt category and indicate the factors arranged as the author would have inserted them in the spaces of charts similar to Fig. 7.

DISCUSSION

Carl J. Allen and Morgan Christensen:* The maintenance data presented in this paper are a most welcome addition to the small amount of information now available. The author should certainly be commended for this valuable contribution.

The presentation in the author's Fig. 1 of the causes of light loss from a lighting system is very helpful in visualizing the various influencing factors. It would seem that the factors of temperature, voltage and ballast design should not be considered a part of maintenance because these have an effect on initial as well as maintained illumination level. The same could be said for obstructions in the space such as conveyors, beams, trusses and machinery in industrial spaces which can have a substantial effect on the illumination level. All of these should be reflected in a modification of the coefficient of utilization.

An interesting commentary on lighting maintenance over the last ten to fifteen years is that the level of illumination in nearly all well maintained fluorescent installations has not depreciated over the years but has actually appreciated and increased in footcandles. This apparent paradox comes about because the 40-watt rapid-start cool-white lamp used in the author's illustration has increased, on the average, in initial lumen output three per cent per year. This is shown in our accompanying Fig. A. If there were no permanent losses in a system, a 100-footcandle 1950 installation would now show 145 footcandles initially after cleaning and a group relamping. With this compensating effect, probably no installation has experienced the maintenance history as shown in Mr. Clark's Fig. 1.

The depreciation of lamp lumens shown in the author's Fig. 1 seems to be substantially more severe than published data. In Fig. 1, the lamp-lumen depreciation is shown to be about 82 per cent and the luminaire dirt depreciation about 78 per cent. The accompanying illustration (Fig. B) shows the lamp-lumen depreciation for typical spot and group relamping for current F40CW lamps. It is seen that with a 70 per cent of life group relamping the lamp-lumen depreciation is 89 per cent; using Mr. Clark's 60 per cent relamping point, the lamps would only drop 10 per cent at the time of replacement. The lamp depreciation would now be less than half the luminaire dirt depreciation. Mr. Clark's Fig. 1 is thus misleading regarding the relative weight of the lamp-lumen depreciation and the luminaire dirt depreciation, as the method of plotting visually indicates that the lamp's depreciation is susbtantially more than that of the luminaire. Except for very clean environments, the luminaire dirt depreciation will probably be substantially more than the lamp-lumen depreciation in nearly all installations.

The difference between the field and laboratory operation of a fluorescent lamp due to differences that exist between commercial ballast *vs* reference ballast is not a factor which should come under cleaning and relamping lighting maintenance. The maintenance factor is normally considered to be the factor which compares the installation's initial performance with that at a later time in its life. The reference ballasts differ from commercial ballasts in that they are strictly reactors to which a specified laboratory voltage is applied to operate the lamps at design wattage and they do not contain any form of a transformer as do regular ballasts. Thus it is misleading to imply that reference ballasts are high in effi-

*General Electric Co., Large Lamp Dept., Nela Park, Cleveland, Ohio.

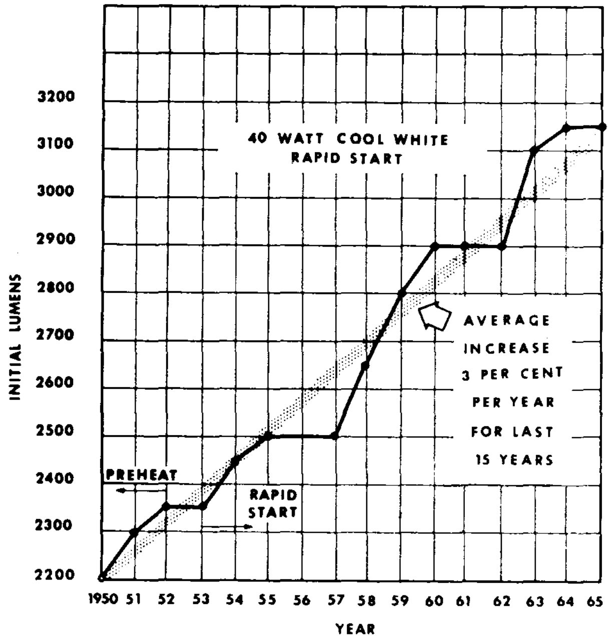


Figure A.

ciency and that, conversely, commercial ballasts are low in efficiency.

With reference to the author's Fig. 1, in that part of the chart between 6 and 12 years, it is not indicated that 50 per cent of the lamps are relamped during the third maintenance phase as compared to 100 per cent relamping in phases 1 and 2, and 33⅓ per cent relamped in the fourth phase. This omission is probably a typographical deletion or omission as the chart indicates that half the lamps are relamped.

While Mr. Clark's method of determining the luminaire dirt depreciation may not be rigorously scientific or accurate to the second decimal point, it does seem a highly practical approach to this long-standing and very knotty problem. It does force the designer to consider the many influencing factors, and the resulting depreciation factor will probably be more realistic than depreciation factors which are based on a broad estimate of the probable situation.

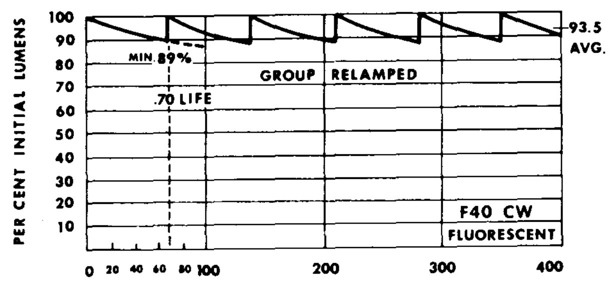
FRANCIS CLARK:* As the discussers indicate, the principal purpose of this paper is to encourage designers to consider all causes for reduction in light output so that they may accurately predict the performance of lighting systems. If the paper does serve this purpose, it has fulfilled the author's hope, regardless of minor differences in terminology, etc.

Probably the explanation for variation between laboratory and field performance of lamps is ineptly presented. Nonetheless, manufacturers' published lumen values are seldom realized in the field, principally because of ballast characteristics, as well as improper ambient temperatures and voltages. It is quite possible these three causes of light loss, being quite constant, should be considered in "Coefficient of Utilization." However, they are not—and the author believes they should not be ignored. It might be noted that these factors reduce the actual lumen output of lamps themselves, whereas obstructions in space prevent a portion of lamp lumen output from reaching the point of measurement or utilization.

Over the years, manufacturers' improvement in initial lumen output of their fluorescent lamps has truly been of great value to the lighting industry and to the public. But it would certainly be rash for a designer to depend entirely on this upward trend in place of proper consideration of "Maintenance Factor." The author, in Fig. 1 and elsewhere, has of course referred to reductions in lumen output as percentages of initial—not as specific amounts of lumens—so the maintenance history would appear to be relatively valid for any lamps, whether 2200, 3150, or 15,000 lumens.

The discussers are correct in their criticism of the difference between published data and the author's representation of lamp-lumen depreciation. The author's experience does definitely indicate poorer field performance than published data would indicate. However, there is another factor which, though much smaller, is misleading. Lacking facilities, patience, or opportunity for continuous large-scale, full-term testing, much of the data were procured in the following manner. At time of cleaning and relamping, measurements were taken at constant, controlled locations, showing output of (1) dirty luminaire and dirty depreciated lamps; (2) clean luminaire and clean depreciated lamps; (3) clean luminaire and clean, new lamps; and (4) appropriate adjustment for pre-100-hour surge of lamps.

Knowing exactly when this installation and specific luminaire were previously cleaned and relamped, the percentage gained by "cleaning only" can be reversed to represent luminaire dirt depreciation for the period between. The same is substantially true for lamp-lumen depreciation—and such figures were used. However, the author recognizes that in practice the comparison is thus frequently being made between depreciated lamps which were initially less efficient than those being presently installed, and undepreciated lamps which are initially more efficient than those presently being removed.



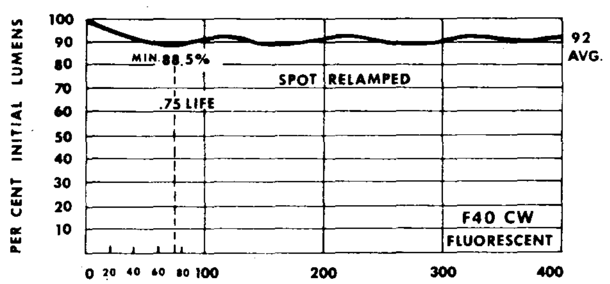


Figure B.

*Author.