Accurate Maintenance Factors—Part Two (Luminaire Dirt Depreciation)

By Francis Clark

TRANSACTION IES

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

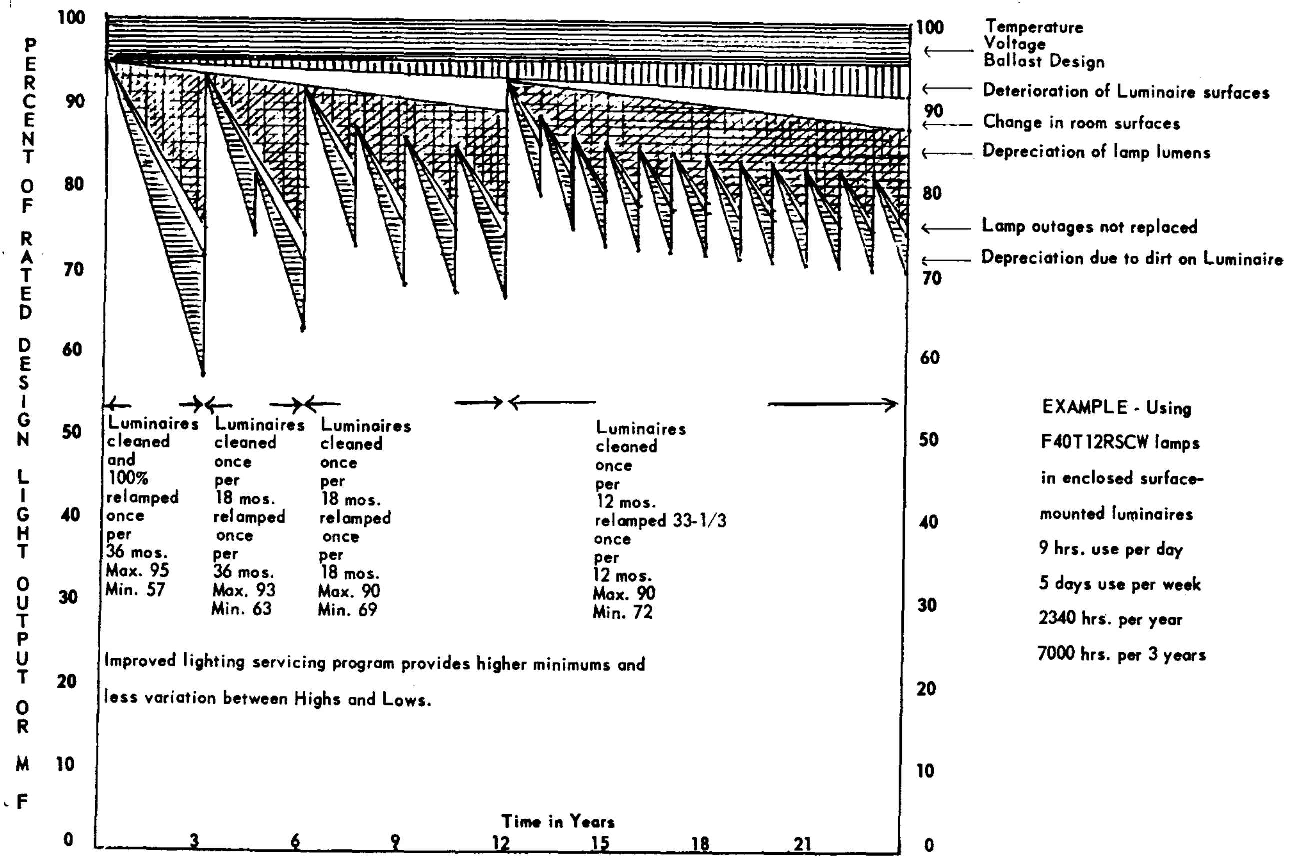


Figure 1. Causes of light loss (cumulative effects).

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.

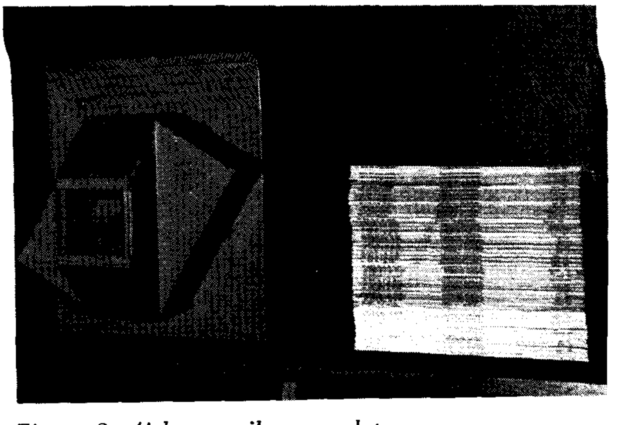


Figure 2. Airborne-soil accumulator.

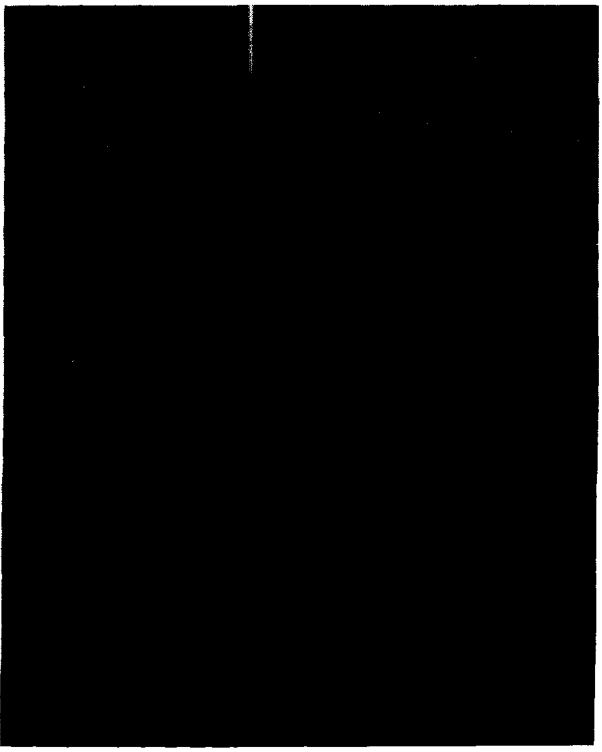


Figure 3a. Accelerated-testing device—exterior.

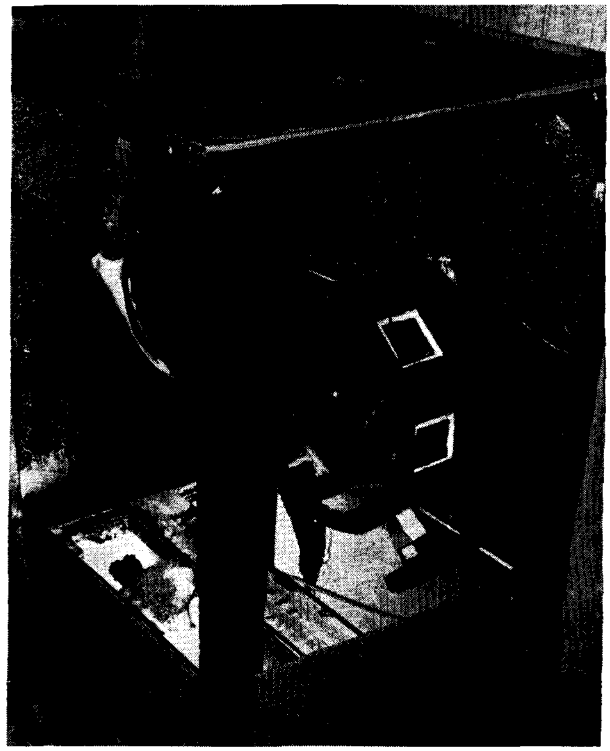


Figure 3b. Accelerated-testing device—interior.

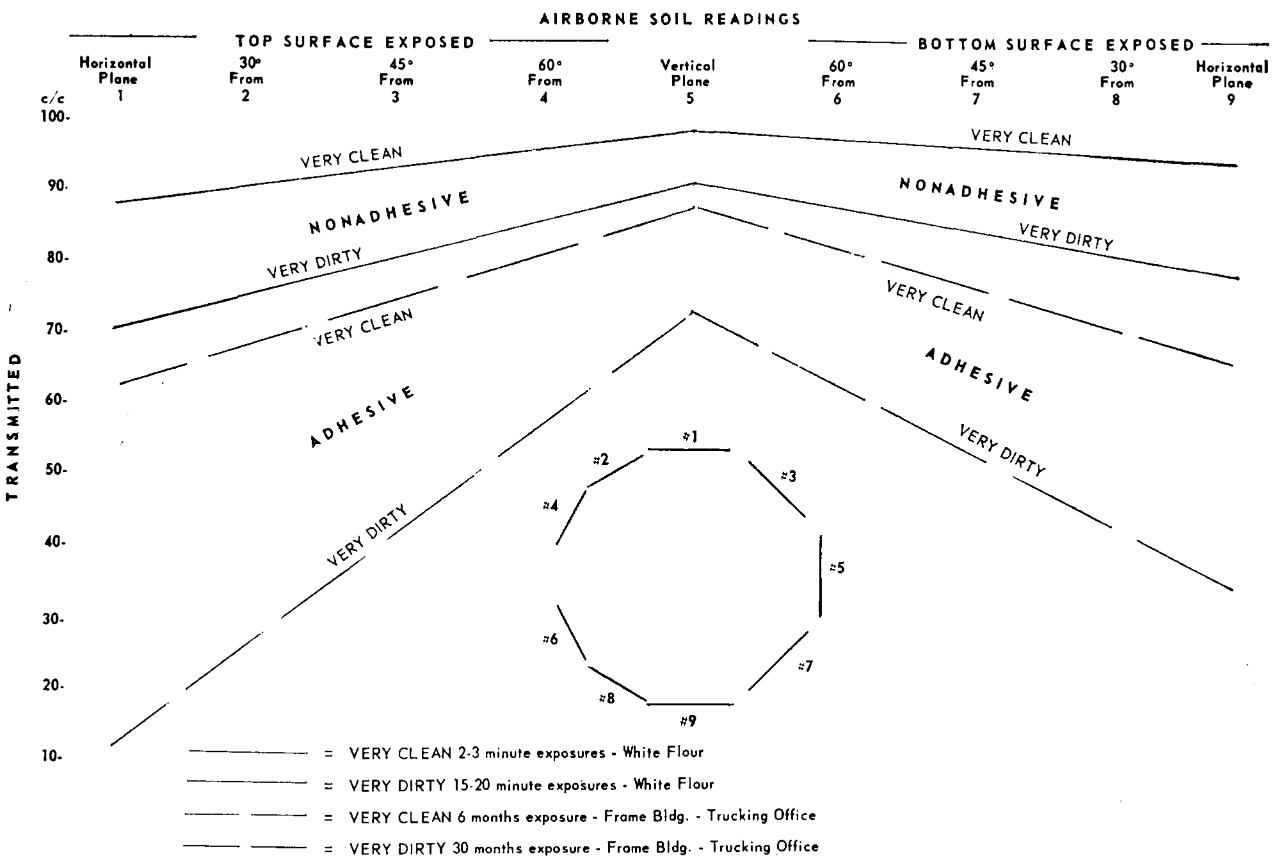


Figure 4. Test-result averages from airborne-soil accumulator and accelerated-testing device.

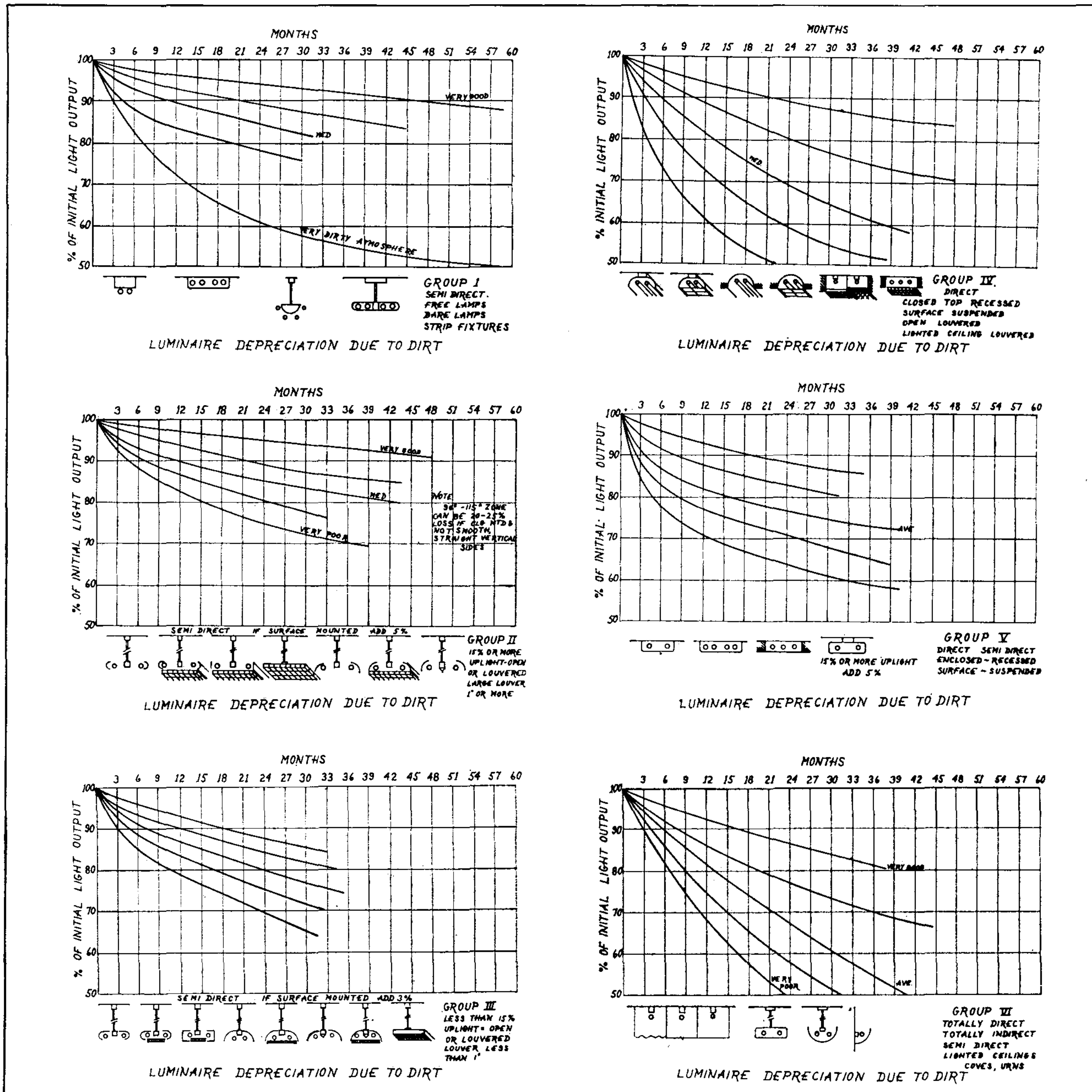


Figure 5. Graphs showing dirt depreciation curves for luminaires grouped according to their similar rates of depreciation.

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 Elec-trostatic		+		=		×		=		+		+		=	
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

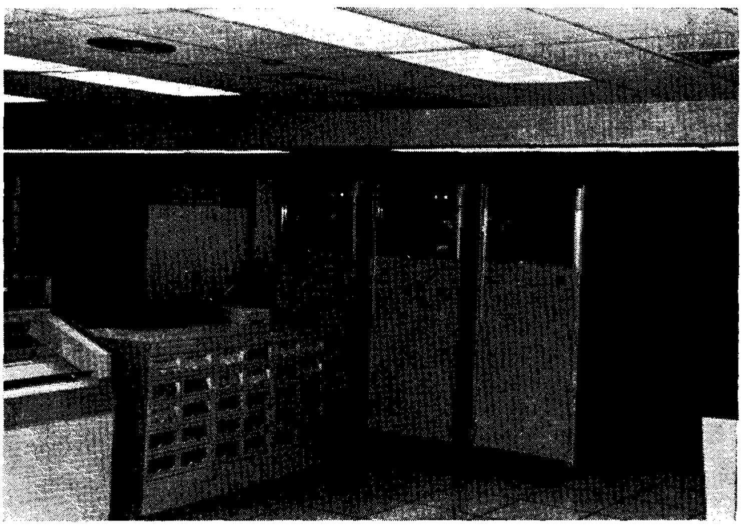
Figure 8. Crowded office open to dirty commercial area—Medium (30).
3 – 4 – 7 – 0 – 7 – 4 – 3 — 14
0 – 0 – 0 – 0 – 0 – 0 – 0 — 0
4 – 4 – 8 – 0 – 8 – 4 – 4 — 16 — 30

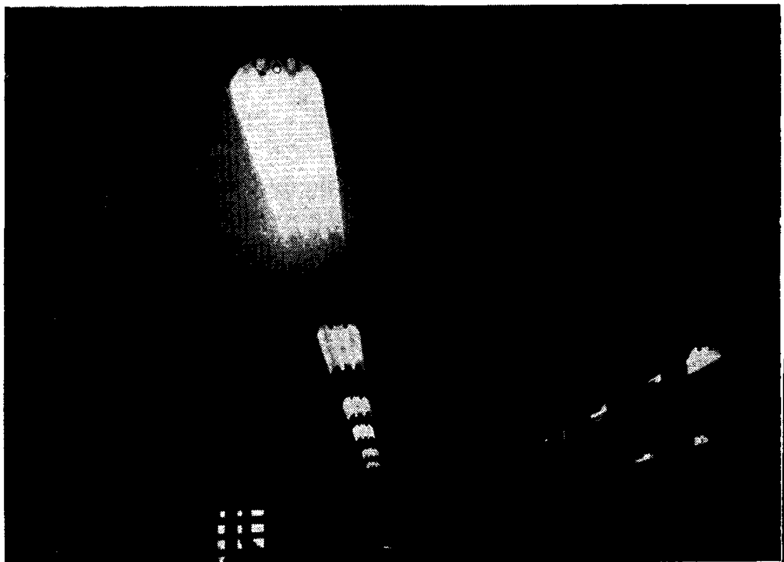
varied from 50 to 95 F and relative humidity from 35 to 75 per cent depending on outdoor conditions and the functioning of unit air conditioners and steam radiators. Oil vapors and exhaust fumes from the trucks and sand and cinders from the unpaved turn-around yard were always present. Dirt generated 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





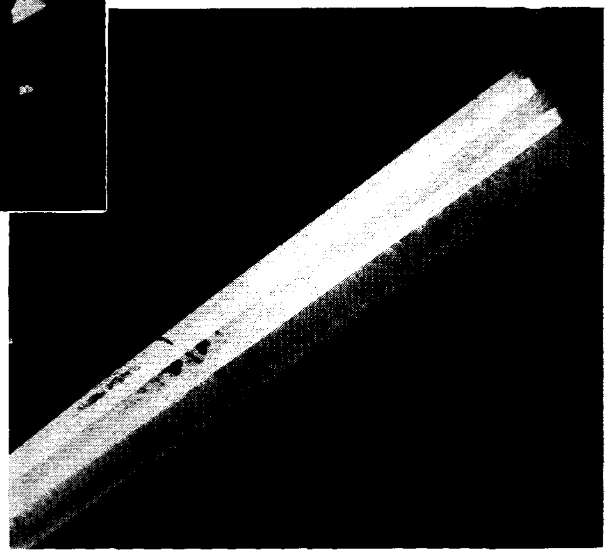


Figure 10. Aluminum plating, open to dirty industrial area—dirty (38). (Above) General view. (Right) Luminaire close-up
4 - 4 - 8 - 0 - 8 - 5 - 5 — 18
1 - 1 - 2 - 0 - 2 - 1 - 1 — 4
4 - 4 - 8 - 0 - 8 - 4 - 4 — 16 — 38

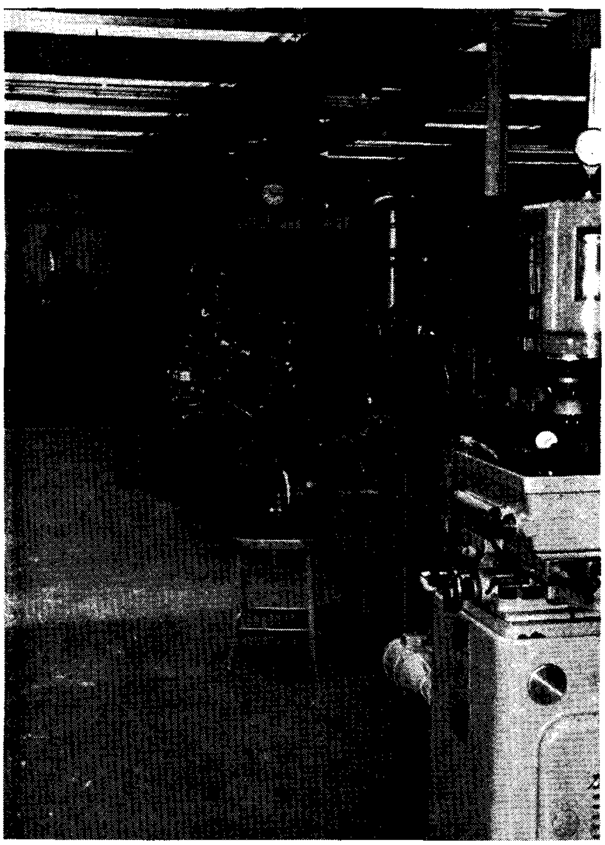
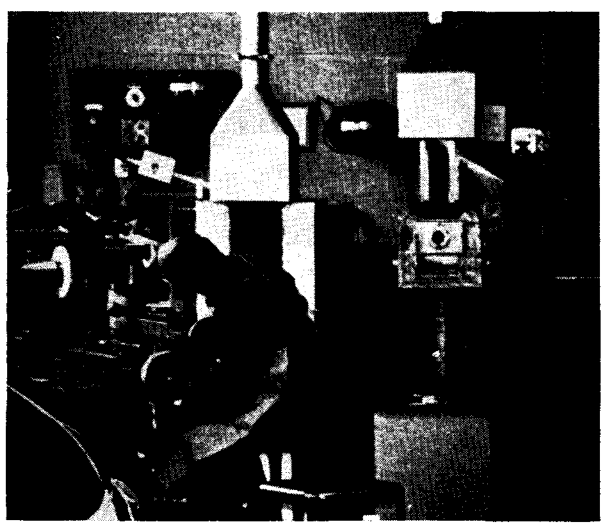


Figure 11. Neat tool and grinding, air conditioned and filtered—very clean (8). (Left) General view. (Below) Close-up.
3 - 2 - 5 - .1 - 1 - 2 - 1 — 4
0 - 0 - 0 - .1 - 0 - 0 - 0 — 0
3 - 3 - 6 - .1 - 1 - 2 - 1 — 4 — 8



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.

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

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-

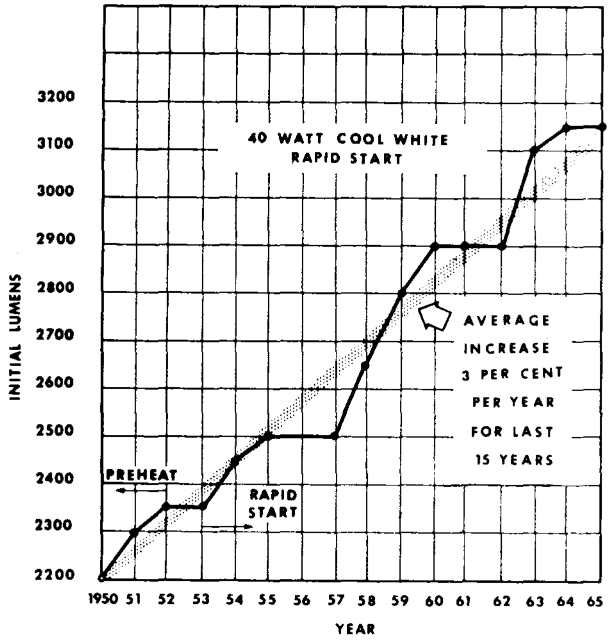


Figure A.

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.

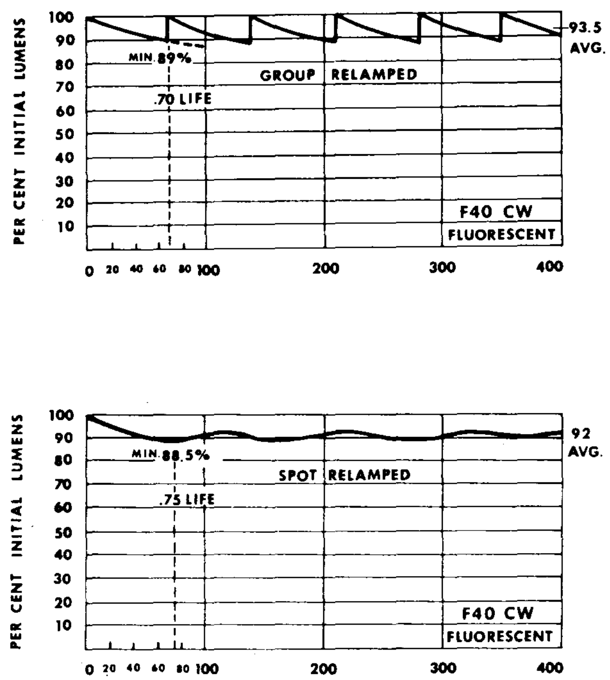


Figure B.

* Author.