The photometric connection—Part 3

Meters and field measurements are discussed

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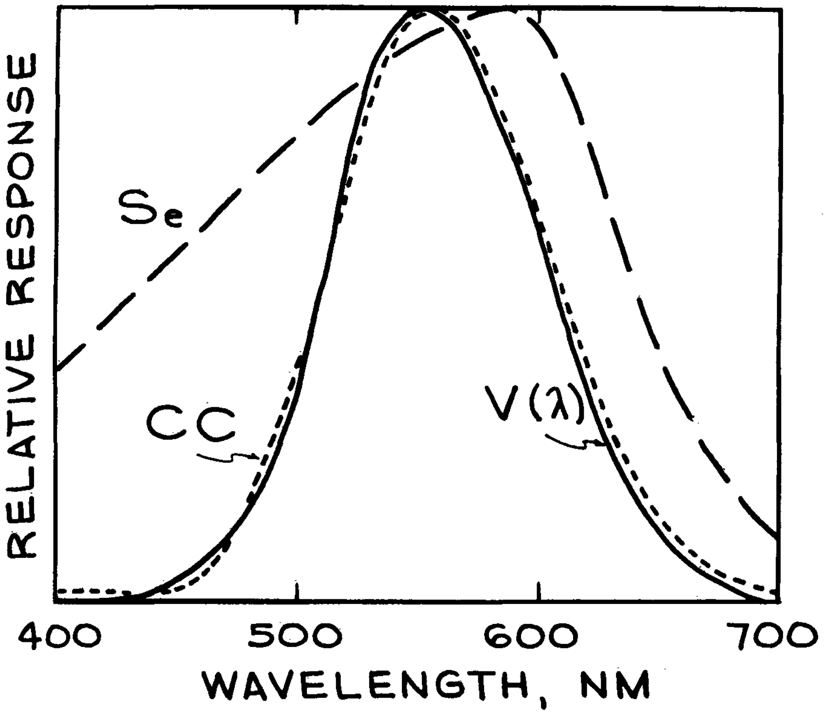
Meters

Having considered lamps, luminaires, and calculations, it would not do to overlook lighting measurements. While there is an extensive catalogue of potential instrument problems, we will briefly survey a few of the most important.

The author: GTE Products Corporation, Lighting Group; Salem, MA. This is a series in four parts: Part 1: photometric testing, luminaires, lamps (Sept. *LD&A*); Part 2: lamp operation, goniophotometers, lighting design (Oct. *LD&A*); Part 3: meters, field measurements (Nov. *LD&A*); and Part 4: discussion and rebuttal (Dec. *LD&A*).

[9] Spectral response of photodetectors. (Se)—selenium cell; (CC)—color-corrected selenium cell; V (λ)—photopic response function.



Light meters (illuminance meters) invariably are color corrected. Essentially, the basic photodetector does not have a wavelength response matching the defined standard visual observer. Referring to [9], (Se) is the spectral response of a selenium cell while V (λ) is the defined photopic visual response function. To illustrate the problem, we could calibrate the cell to read properly at one wavelength, say at 550 nm, but if it were used to read light of 500 nm it would obviously read over 100 percent high. If a cell were calibrated for one light source spectral distribution, it would always read that distribution properly. When the spectral distribution changes, the reading is no longer correct.

Calibration is normally established using an incandescent source. By adding proper filters to a cell, it can be color corrected such that other light sources can be measured. Curve (CC) of [9] illustrates a typical correction. No one has yet been able to make perfect correction. For broad spectrum white light, this correction is usually satisfactory, but if a major portion of the power from a light source were localized, a large error could still exist. For example, statements are often made to the effect that color correction is to ±3 percent *of maximum*. However, the fractional error at a given wavelength can be massive. Figure 10 shows the relative spectral response as measured on several color corrected detectors. This form of presentation is superior to that of Figure 9 for evaluating color correction.

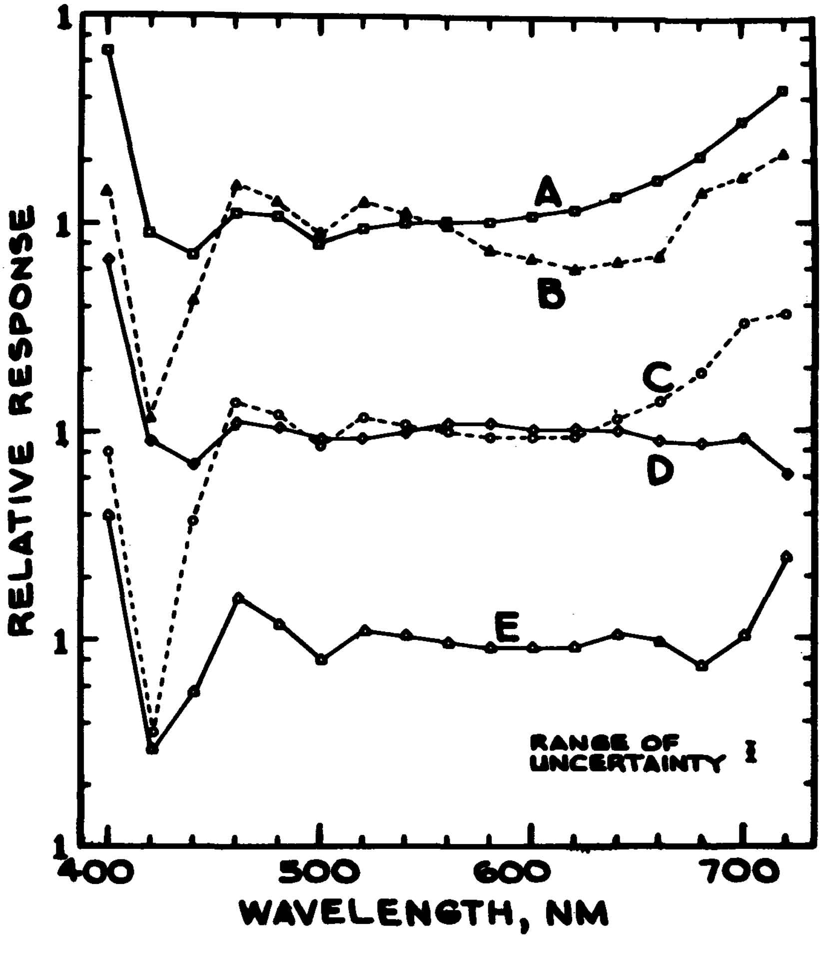
[11] shows a test made with perpendicular illumination on a well corrected cell. Several light sources were used, and the illuminance of each was adjusted within a range of about ±2 percent by spectroradiometry. The cell response was remarkably consistent except for strong red and blue sources. All color corrected cells are not this good, and the color response can be a function of other parameters such as angle of incidence on the cell. As a basis of comparison, the response of an uncorrected selenium cell is included in Figure 11. Photomultiplier tubes are generally more difficult to color correct than selenium and silicon detectors, and there is the possibility of a long term drift in the spectral response of such tubes.

A second principal correction is required if the light to be measured does not come from essentially a single direction. Referring to the sketch in [12], the illuminance (E) at a point on a plane decreases with the cosine of the angle of incidence (θ) for constant intensity (I). A light meter must mimic this spatial relation, but photodetector cells do not inherently do this. Curve (C) shows a particular uncorrected detector to illustrate the type of response that can occur. Since meter calibration is invariably performed at normal incidence (0°), a measurement for light at 70° would have an error in excess of 50 percent.

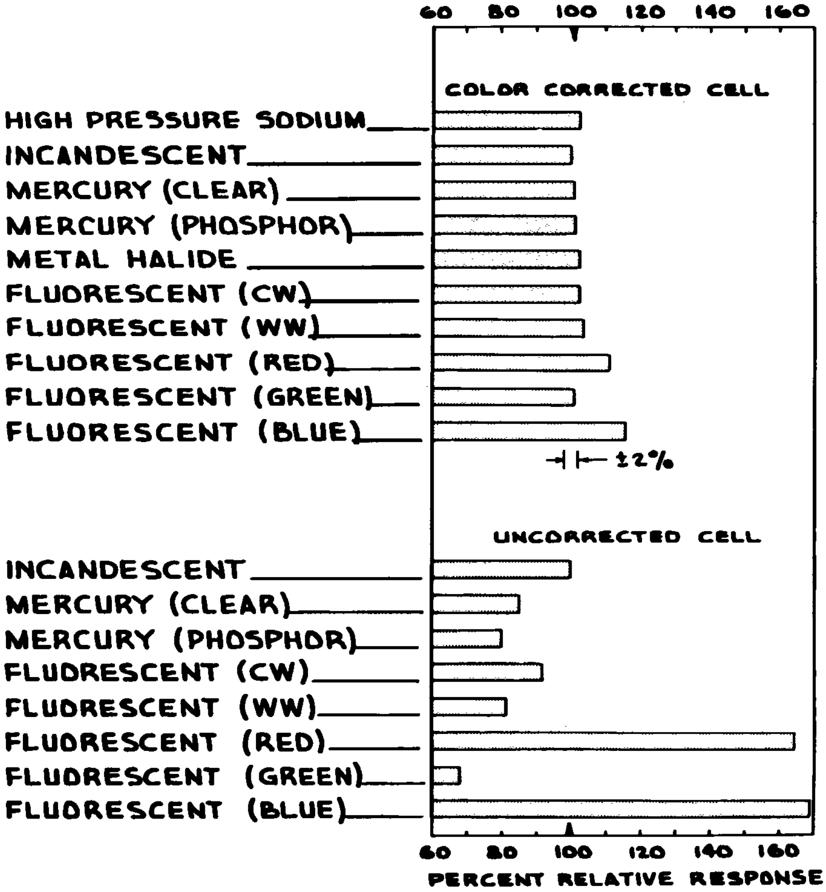
When light is incident from one direction, it is possible to place the cell normal to the direction of the light and multiply the reading by the cosine of the angle of incidence to the surface. However, when light is incident through a range of angles, the meter must be cosine corrected. Cosine correction is usually recognizable due to the presence of some type of white diffuser over the cell. The mere presence of such a diffuser does not guarantee adequate correction. A test on one expensive "cosine corrected" light meter a few years ago produced the curve labeled (B). Several instruments are available with responses similar to curve (A). The departure from the cosine function is sometimes quoted as a percentage of the maximum (the 0° value); this is not adequate. The fractional error at each angle is the significant factor.

The third major problem is that of absolute calibration. One often sees the statement that an instrument is calibrated with a source traceable to NBS. What does this mean? Each succeeding transfer in a chain of calibrations introduces an additional uncertainty. A meter will be calibrated against a lamp which is a working standard; its calibration in turn is obtained from a higher order standard which is preserved by infrequent use. This process may track through one or more laboratories before deriving from NBS

[10] Measured relative spectral response for several color corrected detectors. A–D, silicon; E—selenium. (BW ~7 nm).

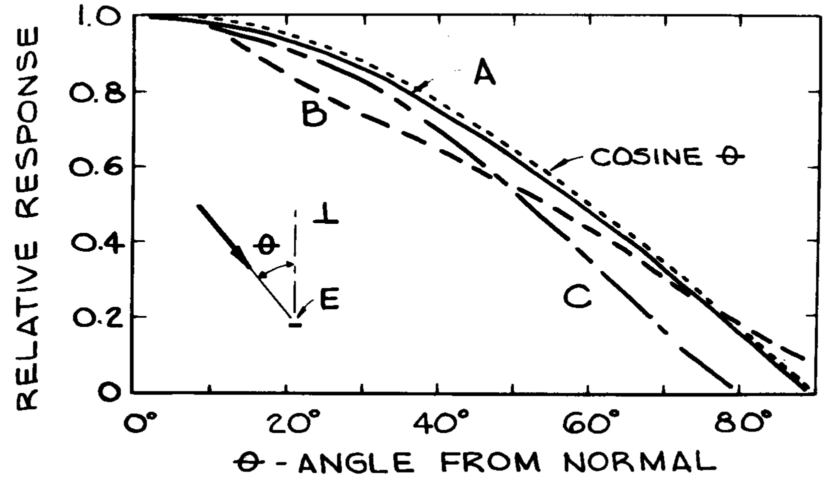


calibrated lamps. And of course, the calibration of these NBS lamps will not be directly from a primary standard. One can ask how well some of these standard lamps have been maintained and how well the various tranfers have been made. Fortunately, those involved in standardization try to follow practices that maintain good accuracy throughout. One is still left with no knowledge about the uncertainty introduced in the actual meter calibration process. Thus, a statement of traceability in itself is meaningless.



[11] Response of color corrected and uncorrected selenium cells to a variety of light sources. Equal illuminance is provided by all sources.

[12] Spatial response of photodetectors. (A) good cosine correction; (B) poor cosine correction; (C) cell without cosine correction.



A review made in 1977 states[21]: "The uncertainty of luminous intensity calibrations performed at NBS has been estimated to be 1.5 percent relative to the candela maintained by NBS, 2.3 percent relative to the world mean, and 4.1 percent relative to the SI unit." This sheds some light on what is possible under the very best of conditions.

Laboratory quality light meters are frequently certified to an accuracy of ±5 percent. Hopefully, this is against the NBS maintained value, but one cannot be certain from the simple statement of accuracy. Manufacturers do not supply propagation of error analysis with measurements establishing the uncertainty at each step. Also, calibration is under a set of test conditions including normal incidence, an incandescent source of specified color temperature, etc. All deviations from the calibration conditions can decrease the accuracy

Inexpensive portable light meters, often called pocket light meters, are not as accurate. Frequently, accuracy is stated to be ±10–15 percent. To give some idea of real conditions, a set of light meters of different types and manufacture were tested. The meters were either new or else had been carefully maintained with all suitable precautions. An incandescent calibration source was arranged for normal illuminance. A level of 860 lm/m^2 was established directly from NBS issued standard lamps; while it is estimated that the uncertainty was less than ±3 percent, the principal interest is to intercompare the instruments. **[13]** summarizes the test. Laboratory type instruments grouped close to the nominal, in all but one case within about 5 percent. However, the full spread of seven meters was 15 percent. Pocket type meters were not as good. With the care one often sees given to light meters in the field, this quality of operation cannot be automatically expected.

The selenium cell, until recently, was the detector of choice for lighting instruments, and at this time it still is the most common detector in use. Poor linearity is its most serious limitation. A recent test investigated for linearity characteristic for about 110 cells over a range of three orders of magnitude. The cells were of the best grade available and were either new or from well cared for laboratory instruments. **Table 6** briefly summarizes the results, and **[14]** illustrates the responsivity of a very good cell (A) and of a poor cell (B). Good cells can be assured only by selection; the alternative is to use the specific responsivity of a cell at each illuminance level. This type of problem is not limited to the manufacture of light meters but also applies in the laboratory where such cells are routinely built into photometric instrumentation. Selenium cells have other well documented problems such as fatigue effects and damage by the high ambient temperatures.

Table 6—Selenium cell linearity (3-3000 Lm/m^2; 110 cells)

Descriptive Category	Approximate Departure From Linearity (%)	Percent of Group
Very Good	<3	11
Good	3-6	35
Acceptable	6-12	29
Poor	12-20	15
Very Poor	>20	10

The newer silicon type detectors are usually preferred today for many reasons. For example, linearity of better than one percent over several orders of magnitude is readily available. Regardless of which type detector is used, precautions are necessary for measurements of high accuracy. Examples of typical concern would be a temperature dependence on the order of 1/10 percent per degree Celsius, the effect of polarization of incident light, etc.

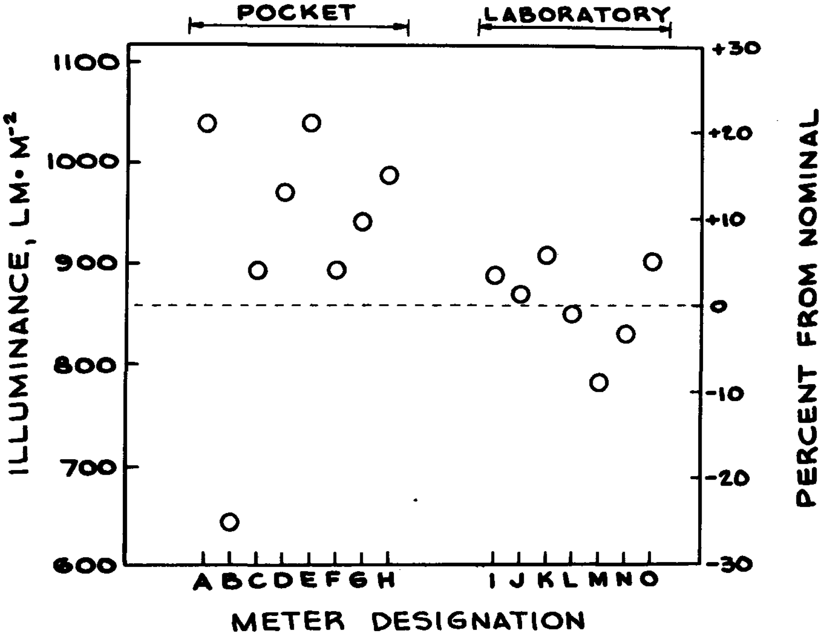
Luminance meters have additional problems associated with the optical system. This might be as simple as parallax in the aiming system. There are more surfaces which can collect dirt and thus affect calibration. In general, instrument defects are less obvious than for light meters, and frequent calibration checks are even more essential than for light meters.

Light meters respond directly to the light incident on the instrument. Luminance meters selectively respond to light incident on the instrument depending on the direction of the light. Luminance meters should uniformly average, *i.e.*, equally weight, all points within the field of view.[22] In practice, there is always some variation from this ideal situation.[23]

It is extremely difficult to design a luminance meter that completely rejects light outside of the nominal acceptance zone. If a region of high luminance is angularly near a low luminance being measured, scattered light within the instrument can imperceptibly cause a false reading. Dirt on the lens can radically enhance this effect.

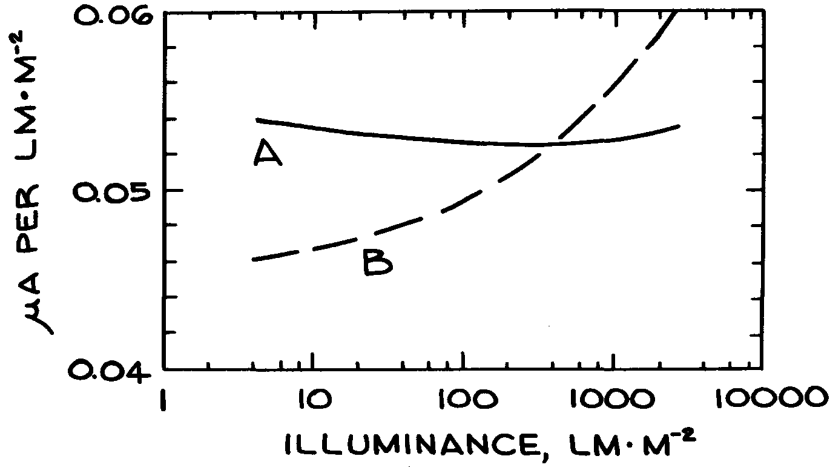
As demonstrations of these problems, two different types of luminance meters which would be classed as laboratory quality instruments were used in the following tests. A 3/4°, 2 cd/m^2 circular target was surrounded by a 3° field of 900 cd/m^2. A thick layer of dust had been allowed to accumulate on the front lense of a 1/2° field of view luminance meter. When the instrument was focussed completely within the target region, a reading of 10 cd/m^2 was obtained. The reading reduced to 2 cd/m^2 after the lens was cleaned. While the dust reduced the instrument response, it scattered sufficient out of field light into the field that the reading was increased.

A 1° field of view luminance meter was focussed into a light trap. A ¾° diameter, 3×10^4 cd/m^2 source was



[13] Response of a group of well-maintained light meters tested under normal calibration conditions.

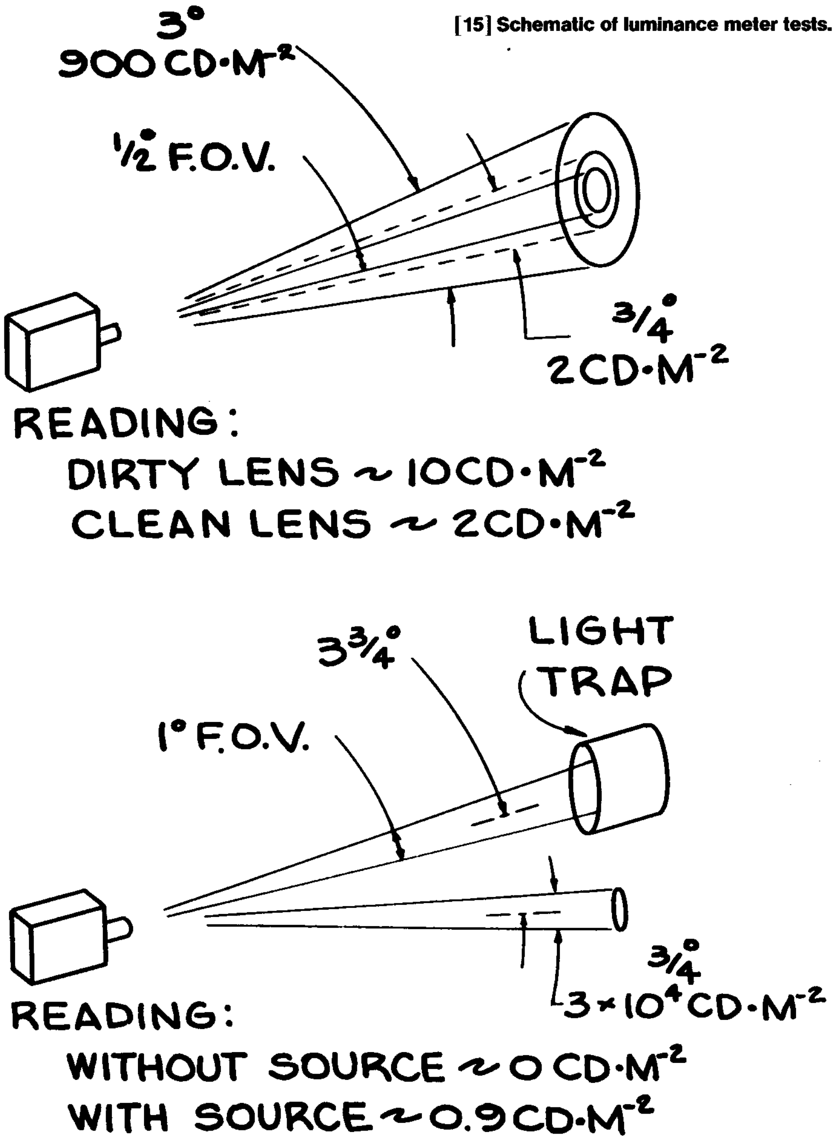
[14] Responsivity of selenium cells under standard incandescent calibration source.



placed 3-1/4° from the center of the instrument field. When the source was turned on, the instrument response increased from zero to 0.9 cd/m^2. These experiments are schematically illustrated in [15].

Field measurements

A few words must be said on the measurements of lighting systems, but we will not dwell long on good engineering practices. For example, it should be obvious that one does not stand so as to shadow a light meter when taking a reading. However, there must be a conscious recognition of the possibility since obvious and well-defined shadows will not be observed under highly diffuse lighting. When an artificial lighting system is being measured, daylight must be excluded. Obvious? This has been overlooked more than once. If the daylight cannot be excluded, then under some conditions it is possible to measure with and without the artificial lighting and then to take the difference. Clearly recording all pertinent factors and conditions during field measurements is essential. Relying on miscellaneous notes and memory generally invalidates retrospective evaluation of the tests.



[15] Schematic of luminance meter tests.

Determining voltage at the time of the test is essential. It may also be necessary to monitor the voltage over a period of time in order to estimate possible variations in lighting or to identify causes of abnormal equipment operation. This must be monitored for an anticipated full cycle over which all probable fluctuations occur. For example, if the lighting is used essentially continuously, then voltage should be monitored for at least a week since day to night and weekday to weekend variations in voltage are common as system loads change.

The voltage of interest is that at the luminaire with the luminaire operating. The meter must have an accuracy of one-half percent or better. It must *respond* to the root-mean-square voltage, especially if solid state controls are present, since luminous output is a function of RMS voltage. Many types of voltmeters are *calibrated* in terms of RMS for a sine wave but *respond* to some other function of voltage.

Temperature is important when measuring fluorescent lighting systems. In addition to determining the ambient temperature, the lighting system should be operated until the luminaire temperature stabilizes; this may require several hours.

For most types of lamps, the change in light output is significant during the first few hours of operation. Then the rate of change decreases noticeably. Consequently, rated "initial" lamp lumens are determined after seasoning, *i.e.*, after a short period of burning; for example, this is 100 hours for fluorescent lamps. Lighting system measurements should not be made until new lamps have been operated for a time comparable to the seasoning time.

Illuminance at specific point is frequently the parameter of interest. However, the average work plane illuminance must be measured to correlate with zonal cavity calculations or to check many typical specifications. Where does one measure the average? Obviously, many points must be measured and an average value calculated. But there are pitfalls for the unwary. As an example, consider a 30 ft by 30 ft classroom. The illuminance might be measured on each desk because "this gives many readings over the room and represents the principal work stations." If the measurements are made through the central part of the room up to a distance of three to four feet from the walls, the calculated average may give a poor measure on the true average illuminance. The illuminance near the walls is generally below the average. Note that this perimeter band is between one-third and one-half of the total floor area; neglecting measurements in this area could artificially elevate the calculated average value. Measurements must be made uniformly throughout the room or else a well designed selective sampling plan must be used.[24]

Although the emphasis has been on interior lighting, it is important to note that the same care must be applied in outdoor measurements. The atmosphere may appear reasonably clear but still produce significant attenuation or scattering for distance luminaires. Extraneous light from signs or buildings frequently is a problem when measuring low light levels. If light is at large angles from the normal as in roadway lighting measurements, the light meter must be leveled. And by measurement, not by judgment; the inability to judge "horizontal" should be well known.

Conclusion

We have seen a range of factors that can lead to significant uncertainties in prediction, measurement, and performance. The lighting engineer will have observed that the list is far from complete, but those factors not reviewed are generally of lesser importance. For example, fluorescent lamp ballast factors are determined on cold ballasts. The ballast factor at normal operating temperature can vary, but usually by not more than one percentage point. This is not taken into account in any part of standard rating or calculation procedures.

At this point there is a salient question, "With the uncertainties that exist, how are we able to get by in normal lighting practice?" The answer is too complex to resolve here. Some of the obvious aspects can be summarized as follows. Allowance frequently is made in practice for many of the factors; even if the allowance is only approximate, it will serve as a partial correction. Also, the various errors tend to be independent events so that, statistically, the total error is not expected to be as large as the sum of the individual errors. When discrepancies are observed, it is not unusual to rationalize by attributing them to some specific cause although careful investigation might reveal that a variety of other aspects were collectively more significant.

This collection of problems has been discussed with various engineers and photometrists. A limited consensus has been developed on the magnitude of discrepancies that might be considered normal. Recognize that these values are only opinions and generalizations. They are a guide in the sense that larger differences tend to be suspect and are worth serious investigation. When luminaire photometery is performed with all due care, laboratories should agree on a given luminaire within one to two percent on fluorescent luminaires, within about five percent for mercury and high pressure sodium luminaires, and to not worse than 10 percent for metal halide luminaires. Again, when all due care is taken, calculations and field measurements of illuminance are anticipated to agree within ±10 percent for indoor fluorescent lighting systems although this could significantly increase when the lighting system involves low energy components. For outdoor lighting, the average illuminance difference might be on the order of ±10 percent but illuminance at specific points could have reasonable differences up to ±50 percent.

If the question "Can we predict luminous quantities and then confirm them by measurement?" is asked, then a strict simplistic answer must be: "Only by chance!" Observe that this is not a realistic reply. Uncertainties are associated with all measurements and with the operation of all physical systems. The connection between prediction, operation, and measurement can be considered under control when variances are both stable and economically acceptable and when biases are reduced to practical limits. It is of extreme importance to recognize and understand all of the factors which contribute to variability and uncertainty. Only on this basis can the problems be rationally resolved. The material and further references in the two volumes of the *IES Lighting Handbook* (Reference volume and Application volume) constitute an excellent start for more information on this subject. ☐

References

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