

Digital Billboard Recommendations and Comparisons to Conventional Billboards

by
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Abstract

This report summarizes several research projects undertaken related to billboard lighting. The topics that have been addressed are:

- Development of digital billboard luminance recommendations
- A comparison of luminances of conventional billboards and digital billboards
- “Sky Glow” lumens entering the night sky from conventional and digital billboards.

i. Digital Billboard Luminance Recommendations

Lighting Sciences, Inc., has undertaken research to develop a method for specification of luminance (brightness) limits for digital billboards based on accepted practice by the Illuminating Engineering Society of North America (IESNA). The recommendation is extremely simple to implement and requires only a footcandle (fc) meter to be used.

The research establishes criteria for billboard luminance limits based on billboard-to-viewer distances for standardized billboard categories. For example, a standard billboard-to-viewer distance of 250 feet is used to establish the billboard luminance limits for a 14' x 48' foot (672 sq.ft.) bulletin.

The recommended technique is based on accepted IESNA practice for “light trespass.” Previous outdoor lighting research has documented an established limit on the amount of light arriving at a person’s eyes to ensure that the source of the light is not offensive, or worse, potentially dangerous. The technique is simple: the light level at the eye is measured in footcandles and has an upper limit. The limit is low for areas that are generally quite dark, but considerably higher in well lit urban areas.

A recommended specification for digital billboards is to use a limit of 0.3 fc over ambient light conditions. To check if the level is acceptable, a footcandle meter would be held at a height of 5 ft. (which is approximately eye height) and faced towards the billboard at the desired billboard-to-viewer distance. A reading of 0.3 fc or less above ambient light conditions would indicate compliance. It should be noted that the footcandle level produced by the billboard is characteristic of the billboard only; because the value of 0.3 fc is *above ambient*, it is not affected by whatever the ambient level may be.

The standards set forth in the report are based on the worst-case scenario of a driver or pedestrian viewing the display head-on (directly at a 90-degree angle), while in practice most displays are viewed at an angle. Since displays are generally viewed at an angle, the luminance (glare) is substantially reduced.

Furthermore, the report provides values for billboard luminance of different color images and notes that luminance levels are based on a worst-case scenario of an all-white display, which is unlikely to happen, save for a malfunction. Knowing these values, and having established a billboard luminance limit for a particular billboard, the allowable percentage of dimming setting is also easily calculated .

The investigations and this report do not cover factors related to changing images and billboard message movement. Issues that may be related to motorist attention are beyond the scope of the work and use of the proposals in this study should be based on that understanding.

ii. Comparison of Conventional and Digital Billboard Luminances

A study by Rensselaer Polytechnic Institute Lighting Research Center has measured the luminance of typical conventional billboards and has developed the maximum value of luminance that can be expected. LSI has compared the recommendations developed in this report to the Rensselaer measured values. The digital billboards will be brighter, but only slightly brighter, than the maximum luminance of conventional billboards.

iii. Sky Glow

Sky glow is caused by lighting at night entering the atmosphere and being scattered by airborne particulates. Sky glow may result from the use of lighting fixtures that emit light above a horizontal plane so that it enters the atmosphere directly. The effect also is caused by light reflecting from lighted objects, such as a road surface, a building or a billboard.

The study has evaluated the amount of light entering the atmosphere from a variety of lighting installations. Measured in "sky lumens," the results allow a comparison to be made of different lighting systems relative to sky glow. Specifically calculations have been made to compare the sky lumens produced by conventional billboard lighting systems, both three and four luminaire bottom mounted systems lighting a standard 14 x 48ft. billboard, to the sky lumens caused by roadway and parking lot lighting.

Various scenarios have been used for the roadway lighting, combining residential and major highway lighting in a typical neighborhood. Areas have been considered that consist only of roadway lighting, as well as areas that contain both roadway and parking lot lighting.

The results of the study support a conclusion that the vast majority of sky glow is a product of urban development. Even where full cut-off fixtures are used on all roadway and parking lot lighting fixtures, and if there is an average of one billboard per square mile, over 96% of the sky glow produced per urban square mile is from those sources and not billboard lighting, for the

conditions examined. For the examples considered, a single three fixture billboard lighting system produces approximately 2 to 3% of the sky lumens caused by roadway/parking area lighting in the example one square mile area. For a four fixture billboard lighting system, the range becomes roughly 2.5 to 4%. These figures can be prorated. For example, if there are two such billboards per square mile, the percentages are doubled; if there is one such billboard per two square miles, the percentages will be halved.

The exact percentages of sky glow are affected by the density of roadways/parking areas, the type of lighting fixtures used and the lighting level provided, among other factors. It is emphasized that the comparisons herein between billboards, roadway and parking lot lighting do not and cannot provide an estimate of the actual percentage of sky glow attributable to billboards. Significant sky glow is produced by multiple other sources such as ball fields, car headlights, floodlighted monuments and buildings, and other outdoor lighting sources. However, it is apparent that for the scenarios considered, the contribution of billboard lighting to sky glow is small in comparison to that from roadways and parking areas. Excluding these other sources, roadways and parking areas produce 96 to 98% of sky lumens, compared to the 2 to 4% produced per billboard in the example urban square mile.

Digital billboards operating at the luminance levels recommended in this report produce much fewer lumens into the night sky than conventional bottom mounted lighting systems. This is primarily due to the elimination of the external luminaires, but also is a result of the characteristics of the billboard pixel design whereby light in upward directions is reduced in comparison to light sent below the horizontal in the direction of viewers.

Definitions

Luminance. Also known as photometric brightness, this is the “brightness” of the billboard as seen from a particular angle of view. It is measured in candelas per sq. meter, also termed “nits.”

Illuminance. This is the amount of light from the billboard landing on a distant surface. It is measured in footcandles (fc) or lux.

Intensity. This is the candlepower, or concentration, of light emitted in a given direction from the entire billboard.

Reflectance. This is a measure of the proportion, or percentage, of light falling on a surface that is reflected by the surface.

SECTION A – DIGITAL BILLBOARD LUMINANCE RECOMMENDATIONS

A1. Introduction

This report has been prepared for the Outdoor Advertising Association of America (OAAA) under the contract issued to Lighting Sciences Inc. for the development of luminance (brightness) recommendations for digital billboards under nighttime conditions. Extensive investigations have been conducted into methodologies that could be used to develop such

recommendations, specifically addressing environmental impact and possible visibility effects on drivers.

The following approaches can be used:

1. Develop billboard recommendations based on the control of possible glare to which drivers may be subjected.
- or
2. Produce recommendations founded on environmental impact, addressing the subject known as light trespass.

Either of these methods can be used as a viable approach to providing an acceptable practice for the control of digital billboard appearance, though the first method has disadvantages. In analyzing these methods, strict attention has been paid to satisfying the following:

1. The needs of the general public, including drivers.
2. The requirements of local government personnel, who may wish to incorporate language into ordinances related to the use of digital billboards. For this, the procedures must be straight forward and enforceable.
3. The needs of OAAA members, who require effective use of digital billboards, which in turn requires adequate brightness for clear visibility.

The two approaches are addressed below.

A2. Method 1, Specifications Based on Driver Glare

Drivers on roadways at night where virtually any form of lighting is provided are inevitably subjected to glare. Glare may be, for example, from oncoming headlights, street lights, or commercial lighting, including billboards. There are recommended limits to the amount of glare that can be produced by vehicle headlights (from the U.S. Department of Transportation) and by roadway lighting (from the American National Standards Institute and the Illuminating Engineering Society of North America –IESNA.) In particular, the extensive procedures that have been developed by IESNA can, in theory, be used to produce limitations on digital billboard luminance that will ensure that any glare problems created for drivers will be relatively minor, in the order of glare often produced by a street lighting installation.

Lighting Sciences has conducted detailed investigations into this approach, based upon publication ANSI IESNA RP-8-00, “American National Standard Practice for Roadway Lighting.” The basic procedures for such a method would be to specify an allowable average billboard luminance level that would ensure that the glare it produces does not exceed certain limits. These limits would be based on the level of highway lighting that is present. For example, higher billboard luminances would be allowed where a high level of street lighting is provided. Publication RP-8-00 classifies highways into many different types, and there is a set of recommendations for the lighting of each type. Thus using these principles for digital

billboard specifications, there would be many different recommended billboard luminance limits, dependent upon the form of roadway lighting provided in the area.

After much consideration, Lighting Sciences does not recommend this approach for establishing digital billboard luminance limits. The reasons include the following:

1. Publication RP-8-00 describes 14 different roadway classifications. These are based on different roadway types (for example, freeways, major roadways, local roadways). There is a further breakdown based on the level of pedestrian activity, which may be high, medium or low. Basing billboard luminances on this wide range would produce a complex system of specifications that would lack the simplicity and clarity that is our goal.
2. Digital billboards are frequently visible from numerous vantage points. This creates an issue of deciding which of the 14 different categories would be applicable if different levels of roadway lighting exist in a general area.
3. There is further complexity in determining the amount of glare produced by a digital billboard using the methodology of publication RP-8-00. The amount of glare is affected not only by the luminance of a digital billboard, but by its distance from the driver. What distance would be selected to perform the necessary calculations when the driver might view the billboard from a wide range of distances?
4. The amount of glare is affected also by the location of the billboard with respect to the driver's line of sight. This changes as the driver looks in different directions and as his location changes. What billboard position would be used?
5. The extent of any glare produced is dependent upon the billboard size. Recommended limits of luminance, if based on glare control, would be different for each billboard size.

Thus it can be seen that, because of all the variables involved, the establishing of realistic billboard luminance limits based on the RP-8-00 methodology would be exceedingly complex. Even if simplifications were introduced, there would be problems in deciding which luminance limit would be applicable to a given billboard. Checking and enforcement similarly would be highly problematic. For these reasons, Lighting Sciences Inc. has not developed and is not recommending a billboard luminance specification system based upon glare limitations. However, in conducting the detailed study of this method and the second method that follows below, it has been determined that if the method provided below is adopted, billboard luminances will be such that producing a significant amount of glare to drivers from a single digital billboard is unlikely. Situations where a multiplicity of such billboards appear in the driver's field of view simultaneously require further research. More evaluation of this topic is suggested using documents produced by other organizations.

A3. Method 2, Specification Based on Light Trespass

A3.1 Method Overview

“Light trespass” is a term used in the outdoor lighting industry to describe light that falls outside of the area that is primarily intended to be lighted. For example, if the lighting system for a shopping center parking lot causes light to spill over into an adjacent residential neighborhood, this would be considered to be light trespass. High levels of light trespass, as well as being wasteful of energy, may have an appearance that is objectionable. Publication TM-11-00 of the IESNA provides a table of limits of light trespass for various “lighting zones.” These zones range from “no ambient electric light” (dark rural areas) to “high ambient electric light” (typically high use urban areas.) The limits are expressed in terms of the illuminance in footcandles that the light source in question can produce at a person’s eyes, measured above the ambient lighting that is produced by all other sources of light. The limitation values were determined from an extensive human factors research project into the levels of light trespass that may or may not be considered objectionable in the various zones. Application of the limits keep light trespass to a low level that is unlikely to be considered objectionable to most persons.

Digital billboards are not the form of lighting that TM-11-00 was developed to limit. In fact, digital billboards are specifically intended to be seen over a wide area, much of which may be remote from the billboard itself. Nevertheless, the principles of TM-11-00, in terms of the calculation method and the limits it provides, can be examined to determine whether the methodology can form a useful method of specifying billboard luminance limits.

Numerous calculations have been performed to evaluate billboard luminance in terms of the TM-11-00 procedures. The calculations involved are simpler than those discussed above for RP-8-00 procedures, as they simply involve determining the illuminance in footcandles (fc) at the location of the eyes of a viewer. (Referred to as “eye illuminance.”) TM-11-00 provides four different eye illuminance limits depending on the lighting zone, E1 to E4, ranging from very low ambient electric light to high ambient electric light. See table 1. (A description of each type of ambient electric light zone is included in Appendix B.)

Zone		Eye Illuminance Limit (fc)
E1	Very low ambient electric light	0.1
E2	Low ambient electric light	0.3
E3	Medium ambient electric light	0.8
E4	High ambient electric light	1.5

To simplify billboard luminance specifications, it is proposed that all billboard luminance limits, no matter where a billboard is located, are governed by the values given in the above table for zone E2. This will then produce a uniform method that does not require the lighting zone to be known. The logic for choosing zone E2 is based on two considerations. Firstly, it is highly unlikely that digital billboards will ever be used in areas described as zone E1. E1 applies to inherently very dark rural areas where there is almost no electric lighting, such as national parks.

Digital billboards are likely to be used in zones E2 through E4. By using the limitations specified by IESNA for zone E2, the specifications are very stringent; any billboard meeting the E2 limits will be satisfactory for the higher ambient light conditions of zones E3 and E4. On this basis, while any eye illuminance value could be used, this report recommends using only that provided for zone E2.

Providing that a method is available to calculate the billboard luminance that will generate a certain illuminance at the eye of a viewer, the illuminance limits of TM-11-00 can be converted to billboard luminance limits. The conversion formula is provided below. It must be noted, however, that this method is not totally straightforward, for there are variables that must be considered for any given billboard, also discussed below.

A3.2 Determining the Maximum Allowable Billboard Average Luminance

The system for relating billboard luminance to the illuminance produced at the eye is briefly summarized in this section. A more detailed coverage of this topic, and lighting units and terms in general, is provided in Appendix A.

Billboard luminance (which refers to the *average* luminance or brightness of billboard) is expressed in candelas per square meter, cd/sq.m., sometimes termed “nits.” The illuminance produced at the eye, considered as landing on a vertical plane at the eye, is designated E_v and is measured in footcandles.

To determine the maximum billboard average luminance, L , that can be allowed so as to meet a given illuminance limit at the viewer’s eye, E_v in footcandles, the following must be know:

- Area of billboard = S sq. ft.
- Distance from billboard center to observation point = D feet (as measured from a plan view. Differences in height of the billboard and viewer normally can be disregarded, as can lateral angle effects from the billboard face.)

$$\text{Allowable maximum billboard average luminance, } L = \frac{10.76 D^2 E_v}{S} \quad \text{cd./sq.m. (nits)}$$

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For example, to determine whether a billboard meets a particular limit for the IESNA publication TM-11-00, the following steps are taken:

1. Select the applicable lighting zone. It is proposed that E2, an area with a low level of electric lighting, be selected as a standard.
2. Find the applicable eye illuminance limit from table 1. If zone E2 is assumed, this will be 0.3 fc.

3. Determine the billboard size. Assume for example a billboard measuring 10 ft. 6 ins. x 36 ft., giving an area of 378 sq. ft.
4. Assume a distance to the viewer. Use 200 ft. (See discussion below).

These values are entered into formula 1 above.

$$\begin{aligned} \text{Allowable maximum billboard average luminance} &= \frac{10.76 \cdot 200^2 \cdot 0.3}{378} \\ &= 342 \text{ cd/sq.m. (nits)} \end{aligned}$$

It should be noted that the footcandle level produced at viewer's eyes by a billboard is independent of the ambient lighting in the area. Footcandles are strictly additive. If a billboard produces 0.3 fc at the eye and the ambient illuminance is 1.0 fc, the total illuminance at the eye is 1.3 fc. If the ambient level is 2.0 fc, the total illuminance is 2.3 fc. The above methodology establishes the illuminance at the eye produced only by the billboard, independent of the ambient level. The actual measured illuminance is always the sum of that produced by the billboard plus the ambient level.

A3.2.1 Viewer Distance

The distance from the billboard to the viewer, D in the above formula, has a significant effect on the calculated allowable maximum billboard luminance. Billboards are typically viewed over a range of distances, and so the choice of the value of D will be somewhat arbitrary. A short distance such as 100 ft. is probably too small for normal situations, and can produce a very low luminance limit. On the other hand, a very large distance such as 1000 ft. will rarely be applicable because viewers will normally be closer when reading the billboard.

It may be questioned whether a short distance should be used as a standard to guard against possible glare effects produced at the eyes of a person driving past a digital billboard. Considering this, as a driver moves closer to a billboard that is positioned to the side of the roadway and the driver is viewing the road ahead, the lateral angle from the driver's line of sight to the billboard increases. This angular effect causes any glare that the billboard may produce to reduce significantly. (Reference: American National Standard for Roadway Lighting, publication ANSI/IESNA RP-8-00, section A7. Glare reduces as the square of the angle from the line of sight.) Further, as this angle increases, the light intensity (candelas) directed toward the driver's eye decreases, as shown by photometric testing of a sample billboard. (Lighting Sciences Inc. test report no. LSI 21628). This effect also contributes to the reduction in glare as the driver approaches and then passes the billboard. These two effects more than offset other factors in determining the glare produced at the driver's changing location: that is, glare actually reduces as the driver's distance to a billboard that is off the side of the road becomes smaller, assuming attention is on the road ahead.

In discussions with members of the advertising industry, it is apparent that billboard size and viewing distance are related. Larger billboards are used to attract viewers at a greater distance,

while small billboards are provided where the observer is fairly close. On this basis, the viewing distances, D, provided below are suggested for use with the formula, based on four prevalent standard billboard sizes:

Billboard Size	Billboard Dimensions (ft)	D ft.
Small	11 x 22	150
Medium	10.5 x 36	200
Large	14 x 48	250
Very large	20 x 60	350

If there is a specific reason why a value of D other than as given above should be applied for a particular billboard installation, this different value may be substituted accordingly in the formula. It should be noted, however, that use of the above distances for the various billboard sizes, and the billboard luminance values so produced, have been field evaluated and appear to be reasonable.

A3.2.2 Allowable Average Luminance and Billboard Size

For any given billboard size, formula 1 can be used to compute the allowable average luminance by incorporating the suggested distance value from table 2. The results for the standard dimension billboards are provided in table 3.

Table 3
Maximum Level of Digital Billboard Average Luminance
Candelas per Sq.M. (Nits)
Proposed Standard
(Based on IESNA Lighting Zone E2)

Billboard Dimensions (ft.)	D** ft.	Luminance (Cd./sq.m.)
11 x 22	150	300
10.5 x 36	200	342
14 x 48	250	300
20 x 60	350	330

*Based on an illuminance produced at the viewer's eye of 0.3 footcandles.

** Distance measured at ground level to observer facing the billboard perpendicularly

A3.3 Digital Billboard Photometric Testing

A small sample digital billboard was supplied to Lighting Sciences' laboratories in Scottsdale, Arizona for photometric evaluation. This was a Prism electronic display with a 20mm pixel spacing as commercially produced in November 2006 by Young Electric Sign Company. This was tested using a model 6440 goniophotometer in accordance with the approved methods of the Illuminating Engineering Society of North America. Tests were run for the device displaying entirely white, red, green and blue colors respectively. The white color is not formed by illuminating white LED's but rather by a combination of red, green and blue LED's. The white setting that was used was 6800K.

The digital billboard was programmable for different levels of dimming. Tests were conducted to measure the luminance at 10% dimming steps from 100% down to 10%.

It was determined that the actual luminance reduction achieved using the various dimming steps accurately corresponded to within a few percent of the dimming settings indicated on the controller.

Data from the series of tests allow the calculation of the luminance of any digital billboard color for full intensity or any level of dimming. Of specific interest were the luminances of a white display because this is the maximum luminance color, as it is generated by the combination of the red, blue and green LED's.

A3.4 Determining the Allowable Dimmer Setting

If a billboard luminance limit has been established by the methodology described above, the photometric data can also provide the dimming setting to be used.

Results of the testing indicated that the digital billboard produced a maximum average luminance of approximately 7000 cd/sq.m. when displaying a completely white (6800k) image at full power. In the above example, to limit the luminance to 342 cd/sq.m. the dimmer setting can be computed as follows:

$$\begin{aligned} \% \text{ dimmer setting} &= \frac{\text{Allowable luminance}}{\text{Luminance at 100\% Setting}} \times 100 \\ &= \frac{342}{7000} \times 100 \\ &= 4.9\% \end{aligned} \quad \text{-----2.}$$

This example is for a medium billboard size measuring 10.5 x 36'. The dimmer setting will be different for other billboard sizes because the allowable luminance changes per table 3. Table 4 presents the dimming settings calculated in an equivalent manner for the standard billboard sizes.

Table 4

Suggested Dimming Settings
Example for the Digital Billboard as Tested

Proposed Standard
(Based on IESNA Lighting Zone E2)

Billboard Dimensions (ft.)	Dimming Setting
11 x 22	4.3%
10.5 x 36	4.9%
14 x 48	4.3%
20 x 60	4.7%

It should be noted that table 4 is applicable only to the digital billboard that was tested. Different types of billboards will produce different results, and therefore require separate photometric testing. Dimming settings will change from one model to another because each may produce a different maximum luminance.

A3.5 Non-white Billboards

If the digital image will never be totally white, higher % dimming settings can be used while still meeting the luminance limit. The actual measured luminances for the sample billboard measured in 2006 for a 100% luminance setting for different colors are:

White (6800k)	7000 cd/sq.m.
Red	1500 cd/sq.m.
Green	5100 cd/sq.m.
Blue	700 cd/sq.m.

For a normal image that includes multiple colors, the average luminance for a 100% setting will depend on the proportion of colors in the mix. Software and instrumentation is available to analyze billboard luminance when the billboard is being programmed.

A3.6 Monochrome Displays

The same methodology applies to monochrome displays as to the color displays described above. For such displays, Equation 1 is used to calculate the allowable maximum billboard average luminance. To calculate the dimming setting using equation 2, the luminance at the 100% setting for the monochrome display is entered. This value will typically be less than for the white display of a colored billboard, and therefore a monochrome billboard can be run at a higher percentage dimming setting, all other factors being equal.

A3.7 Adoption of the Method

This method uses the established and recommended procedures of IESNA to develop billboard luminance limits. The procedure can be adopted by referring to the limits of IESNA publication TM-11-00 as provided in table 1 above, with the suggestion that lighting zone E2 values be used as a standard. Billboard-to-viewer distances are proposed to be as provided in table 2 above.

Table 3 summarizes the recommended maximum billboard luminance values based on tables 1 and 2. These can be adopted directly into an ordinance or set of guidelines.

The limitations of TM-11-00 were established through research conducted by Lighting Sciences Inc. under a contract from the Lighting Research Office of EPRI (Electrical Producers' Research Institute). The basis of TM-11-00 was subsequently provided to IESNA to form the publication. Field use of the values for various forms of outdoor lighting confirm that the values are realistic and prevent undue annoyance to a majority of viewers, and thus appear to have formed a satisfactory basis for specifying such lighting limits.

The procedures outlined in this section of this report, method 2, specifications based on light trespass, are recommended by Lighting Sciences Inc. for evaluation and possible subsequent adoption by OAAA.

A3.8 Enforcement

After a billboard is installed, there will be cases where it is desired to evaluate the billboard luminance to ensure that it does not exceed the specified value. This procedure is extremely simple and requires only a footcandle meter.

The billboard luminance specification is based on ensuring that a certain footcandle level (above ambient) created by the billboard is not exceeded at a chosen distance. Thus all that is needed to check compliance is the measurement of the footcandles level at that distance with the billboard on and off. The footcandle meter would be held at a height of 5 ft. (which is approximately eye height) and aimed towards the billboard, from a distance as selected from table 2. If the difference in illuminance between the billboard-on and billboard-off conditions is 0.3 fc, then the billboard luminance is in compliance. When conducting this check, the meter should be at a location perpendicular to the billboard center (as seen in plan view) as this angle has the highest luminance.

This check should include the measurement of an all white image displayed by the billboard to evaluate the worst case condition.

A4. Summary of Proposed Method

Specification based on the light trespass limits adopted by IESNA in publication TM-11-00 appears to provide a manageable and technically viable technique.

It is proposed to use the IESNA recommended limits for environmental lighting zone E2, low level electric lighting, as a standard. This limits the maximum illuminance produced by the billboard and measured at the eye of a viewer to 0.3 footcandles over ambient. It is further proposed that the viewer be positioned from the billboard at ground level and facing in a direction perpendicular to the billboard. The distance will be dependent upon the billboard size.

Under these conditions, to meet the 0.3 fc limitations, the maximum allowable billboard average luminance will be as given in table 3 for various standard billboard sizes. The percentage dimmer setting, expressed as a percentage of the billboard maximum luminance, can be calculated from the table 3 luminance value, based on the maximum luminance of a billboard being 7000 cd/sq.m. or some other known value.

Because these values have been derived from IESNA publication TM-11-00, which in turn is based on an extensive human factors research project, adoption of such values should satisfy the requirement that most persons will not find these billboard luminances to be objectionable.

SECTION B – BILLBOARD LUMINANCE : DIGITAL VERSUS CONVENTIONAL

The foregoing has provided recommendations for the average luminance limits for digital billboards. It is of interest to compare these to the luminance levels found with conventional billboards. Such billboards are most commonly lighted using luminaires designed for this specific purpose, manufactured by the Holophane Company. Most installations consist of a series of fixtures that use 400 watt Metal Halide lamps. Typically a 14 x 48 ft. large billboard is lighted by four such fixtures mounted along the bottom edge of the billboard. Some billboards, employ a lighting system using only three bottom mounted luminaires. Other designs may use top mounted lighting in various configurations. An optical refractor or lens is used on each luminaire to direct light onto the billboard, which increases the billboard luminance.

The luminance of conventional billboards has been addressed in a study by the Lighting Research Center of Rensselaer Polytechnic Institute that was sponsored by the New York State Department of Transportation. A technical memorandum has been developed titled “Evaluation of Billboard Luminances” dated March 31, 2008. This memorandum states the following:

“... it is probably reasonable to expect that the luminance of a conventional billboard would not be likely to exceed about **280 cd/sq.m.** during the nighttime (assuming typical lighting practice as represented by the IESNA and industry recommendations, and by the lighting systems used on the billboards that were measured in the field)...”

The report indicates that the value of 280 cd/sq.m. (nits) is consistent with clean billboard lighting systems using new lamps. This is also the condition used for testing the digital billboard at Lighting Sciences’ laboratories as referenced above.

It is thus anticipated that digital billboards operated in accordance with the recommendations developed above, (300 to 342 nits, depending on size), will be brighter, but only slightly brighter, than the maximum luminance of conventional billboards.

SECTION C – SKY GLOW

C1 Introduction

A further factor, “sky glow,” has been addressed in relation to both conventional and digital billboards.

Sky glow is caused by light at night entering the atmosphere and being scattered by airborne particulates. Sky glow may result from the use of lighting fixtures that emit light above a horizontal plane so that it enters the atmosphere directly. The effect also is caused by light reflecting from lighted objects, such as a road surface, a building or a billboard.

It is highly desirable to reduce sky glow in order to preserve dark skies. This is an environmental concern, as well as a significant factor influencing the ability of astronomers to study the night sky.

The amount of light entering the atmosphere from a variety of lighting installations has been evaluated. Measured in "sky lumens," the results allow a comparison to be made of different lighting systems relative to sky glow. Specifically calculations have been made to compare the sky lumens produced by a typical billboard lighting system to the sky lumens caused by roadway and parking lot lighting. Extensive work was conducted for conventional billboards, then later work compared newer digital billboards to the conventional billboards.

Various scenarios were used for the roadway lighting, combining residential and major highway lighting in a typical neighborhood. Areas were considered that consist only of roadway lighting, as well as areas that contain both roadway and parking lot lighting.

It is emphasized that the comparisons herein between billboards, roadway and parking lot lighting do not and cannot provide an estimate of the actual percentage of sky glow attributable to billboards. Significant sky glow is produced by multiple other sources such as ballfields, car headlights, floodlighted monuments and buildings, and other outdoor lighting sources. These have not been included in the analysis as quantitative measures of the sky glow that these produce are not available.

C2.1 Conventional Billboards

A 14 x 48 ft. billboard was evaluated using both three and four bottom mounted Holophane “Panel Vue” fixtures. Each was equipped with a 400 watt metal halide lamp rated at 40,000 lumens. Photometric test data were obtained from the manufacturer and computerized calculations were performed.

All calculations were based on a 0.70 Light Loss Factor, or Maintenance Factor, to account for the reduction of light output as the lamp ages and as the fixture collects dirt.

For both the three and four fixture lighting systems, the following quantities were calculated:

Total uplight lumens emitted by the group of fixtures
Total lumens intercepted by the billboard
Total lumens intercepted by the billboard underboard
Total lumens emitted upwards by fixture that do not strike the billboard or underboard.
(Direct sky lumens)
Total lumens reflected upwards by the billboard
Total lumens reflected upwards by the underboard
Total lumens reflected upwards. (Indirect sky lumens)

The manufacturer's data were used directly; no additional shielding was assumed for the lighting fixtures.

Results obtained for the three and four fixture systems in terms of total sky lumens are as follows:

3 fixture system: 23,415 lms
4 fixture system: 31,535 lms

These values will be affected by the reflectance of the billboard face material, which is dependent on the lightness/darkness of the material. An average value of 25% was used, derived from laboratory measurements of sample billboard face materials. A reflectance value of 2.5% was used for the underboard.

No account is taken in these calculations of the angular direction of the uplight lumens as they enter the atmosphere, which is likely to have some influence on the degree of sky glow that is produced.

C2.2 Roadway Lighting

For this study, billboard lighting was compared to roadway lighting. While it is recognized that there are many sources of nighttime light other than roadway lighting, this form of lighting usually constitutes a major source of uplight lumens.

LSI has produced roadway lighting designs for three different roadway types and has computed resultant uplight lumens, as follows:

Local roadway. Illuminating Engineering Society of North America (IESNA) specification is 0.7 footcandles average maintained lighting level, with a 6:1 average to minimum uniformity. (i.e. The minimum footcandles at any point will not be less than one sixth of the average.)

Collector roadway. IESNA specification is 0.9 fc maintained, 4:1 uniformity.

Major roadway. IESNA specification is 1.3 fc maintained, 3:1 uniformity.

In all three cases, "medium pedestrian conflict" per IESNA was assumed.

A Light Loss Factor or Maintenance Factor of 0.70 was used, so as to be equivalent to the same factor used for the billboard calculations.

For each roadway, lighting system design has been conducted using a flat glass "full cut off" fixture, and the older style "cobra-head semicutoff" fixture with glass bowl lens. The full cut off fixture allows no light to escape above the horizontal, while the semicutoff fixture emits a few percent of its total lumens above the horizontal.

Most existing roadways, particularly where the lighting was installed 15 or more years ago, will use the glass bowl lens. Because of a desire to control sky glow, many agencies have now switched to full cut-off optics. In any urban area, both types of fixtures are likely to be present. By analyzing roadway lighting with each of these fixture types, a realistic range of possibilities is examined.

For all designs, various pole heights were investigated. Each design was optimized to acquire the maximum pole spacing that can be used while meeting the IESNA lighting specifications. Thus the design procedures were similar to those used by typical roadway lighting designers.

For each lighting system, the following were calculated, all on the basis of a single mile of roadway:

- Total lumens falling on the roadway
- Total lumens falling on the ground outside of the roadway
- Total lumens reflected upwards from the roadway
- Total lumens reflected upwards from the ground outside the roadway
- Total lumens emitted upwards directly from the fixtures. (This quantity is zero for the cutoff fixture.)

Typical known reflectance values were used for the road surface and areas outside the roadway.

Results of the computation, given in sky lumens per mile are as follows:

Local roadway, full cutoff fixture:	25,837 sky lumens per mile
Local roadway, semicutoff fixture:	38,079 sky lumens per mile
Collector roadway, full cutoff fixture:	47,652 sky lumens per mile
Collector roadway, semicutoff fixture:	64,071 sky lumens per mile
Major roadway, full cutoff fixture:	153,355 sky lumens per mile
Major roadway, semicutoff fixture:	259,910 sky lumens per mile

C2.3 Comparison of Conventional Billboards and Roadway Lighting

Based on the above values, the sky lumens produced by one billboard using a three fixture lighting system are approximately equal to the sky lumens produced by:

0.91 miles of local roadway with full cutoff fixtures

- or 0.49 miles of collector roadway with full cutoff fixtures
- or 0.15 miles of major roadway with full cutoff fixtures
- or 0.61 miles of local roadway with semicutoff fixtures
- or 0.37 miles of collector roadway with semicutoff fixtures.
- or 0.09 miles of major roadway with semicutoff fixtures

The sky lumens produced by a four fixture billboard lighting system are roughly equal to the sky lumens produced by:

- 1.22 miles of local roadway with full cutoff fixtures
- or 0.66 miles of collector roadway with full cutoff fixtures
- or 0.21 miles of major roadway with full cutoff fixtures
- or 0.83 miles of local roadway with semicutoff fixtures
- or 0.49 miles of collector roadway with semicutoff fixtures.
- or 0.12 miles of major roadway with semicutoff fixtures

As another way of comparing the data, the total roadway lighting per square mile of an urban area can be computed and compared to billboard lighting. An example city square mile has been checked (in Denver, CO). For a typical urban built-up area, the following roadway lengths were present in the selected 1 sq. mile:

- Total length of local roadways: 21 miles
- Total length of collector roadways: 1 mile
- Total length of major roadways: 1 mile

The total sky lumens assuming all roadways are lighted for this square mile have been calculated and are:

- For all roadways lighted by full cutoff fixtures: 743,584 lumens
- For all roadways lighted by semicutoff fixtures: 1,123,640 lumens

If a single billboard is situated in this example square mile, the percentage of total sky lumens created by the billboard lighting is as follows:

- Billboard sky lumens as % of total, for 3 fixture system, when roadways are lighted with full cutoff fixtures: 3.1%
- Billboard sky lumens as % of total, for 4 fixture system, when roadways are lighted with full cutoff fixtures: 4.2%
- Billboard sky lumens as % of total, for 3 fixture system, when roadways are lighting with semicutoff fixtures: 2.1%
- Billboard sky lumens as % of total, for 4 fixture system, when roadways are lighting with semicutoff fixtures: 2.8%

Other assumptions for the density of roadway lighting and number of billboards can be similarly determined. For example, if the roadway lighting is as above, but the density of billboards is halved, the percentage sky glow from the billboards will be halved.

In certain urban areas, the roadway lighting usage may be greater than in the selected example area. There will likely be other sources of sky glow such as vehicle headlights, floodlighting for buildings and sports facilities. In such conditions, the percentage contribution of a given amount of billboard lighting to the overall sky glow will be reduced. In yet other areas, roadway lighting may be less than that illustrated above, and the proportion of sky glow produced by the billboard will be higher. Further efforts under an extended research program could analyze large urban areas and survey lighting usage by types.

C2.4 Parking and Roadway Lighting

As another example scenario, calculations have been made for a 1 square mile area consisting of both roadway lighting and parking lot lighting. In this example, a parking lot size of one quarter mile square has been included. The total length of local roadways has been reduced to 16 miles. The parking lot is assumed to be lighted to an average level of 1.5 footcandles.

Because the parking lot is lighted to a higher level than the roadway it replaces, and because a larger area is being lighting, the total sky lumens are increased versus the earlier example that assumes the presence of roadways only.

The modified values of total sky lumens are:

For all roadways and parking areas lighted by full cutoff fixtures: 836,687 lumens

For all roadways and parking area lighted by semicutoff fixtures: 1,273,028 lumens

If a single billboard situated in this example square mile, the percentage of total sky lumens created by the billboard lighting is as follows:

Billboard sky lumens as % of total, for 3 fixture system, when roadways and parking areas are lighted with full cutoff fixtures: 2.8%

Billboard sky lumens as % of total, for 4 fixture system, when roadways and parking areas are lighted with full cutoff fixtures: 3.8%

Billboard sky lumens as % of total, for 3 fixture system, when roadways and parking areas are lighting with semicutoff fixtures: 1.8%

Billboard sky lumens as % of total, for 4 fixture system, when roadways and parking areas are lighting with semicutoff fixtures: 2.5%

It should be noted that in this analysis, all lumens reflected from surfaces or emitted upwards directly from the fixtures are assumed to enter the sky. This is probably true for most billboard lighting systems. For roadway and parking lot lighting, however, reflected light may be blocked by objects such as buildings or trees. If this blockage is 50%, for example, the above percentage contribution of billboard lighting to sky lumens will be doubled. Nonetheless, even assuming a scenario where all roadway and parking lot lighting sources are fully-shielded fixtures, the sky glow caused by billboards is a small percentage of the overall sky glow, under the conditions evaluated.

C2.5 Evaluation Methodology

The above provides an evaluation methodology based upon certain assumptions; One billboard is situated in a one square mile area, and various scenarios for roadway and parking lot lighting are considered. For analysis of sky glow effects for an actual city, however, it is important to extend the analysis to cover the entire city, taking into account the actual billboards present and other lighting systems throughout the area. Preferably such an analysis will also include sources of sky glow such as ballfields, vehicle headlights, floodlighting installations and other forms of nighttime lighting.

It should further be noted that the percentage sky glow contribution from multiple billboards is not additive. For example, if one billboard in a one square mile area produces 2.5% of the sky glow, 40 billboards in the same area will not produce $40 \times 2.5 = 100\%$ of the sky glow. The net percentage actually will be lower.

C2.6 Billboard Lighting Trends

The foregoing analysis is based on the lighting of 14 x 48 billboards using systems of 3 or 4 400 watt metal halide fixtures per billboard. Trends in lighting systems are towards lowering the number of fixtures used, and to the use of lower wattage lamps. Effective lighting systems are available using 3 or even 2 fixtures per billboard, and in some cases, 320 watt lamps are used. Sky glow will be reduced very approximately in proportion to the total lumens used.

C3 Digital Billboards and Sky Glow

The scenario to be evaluated for digital billboards in relation to sky lumens is completely different from conventional billboards: There is no reflecting billboard surface and no exterior luminaires, as the digital pixels themselves are the light sources. Some light from the pixels is emitted in directions below the horizontal where it provides the advertising message to viewers and some light is emitted above the horizontal where it enters the atmosphere (unless blocked by trees and structures).

The photometric test data for the digital billboard sample tested at Lighting Sciences' laboratories has been examined, and calculations have been performed to determine the sky lumens that will be generated for a typical 14 x 48 ft. digital billboard.

It is significant to note that the digital billboard as tested is designed to direct the majority of its light below the horizontal, in the direction of the viewer location. This is achieved by the use of horizontal louver blades that are angled downwards and that run between adjacent rows of pixels. This is illustrated in figure 1; in this figure, the lengths of the arrows represent the actual intensities of the light rays in the various directions as documented in the laboratory photometric test report. For example, light intensity emitted 20 degrees below the horizontal is more than double the intensity emitted 20 degrees above the horizontal. This has the obvious effect of reducing sky lumens versus that which would be produced if light above and below the horizontal were equal.

Elimination of bottom mounted exterior luminaires commonly used for conventional billboards play a very significant role in the reduction of sky glow. For the example scenario detailed earlier in this report, where a four luminaire bottom mounted system produces 31,535 sky lumens, roughly 90% of those lumens are emitted into the sky directly from the fixtures.

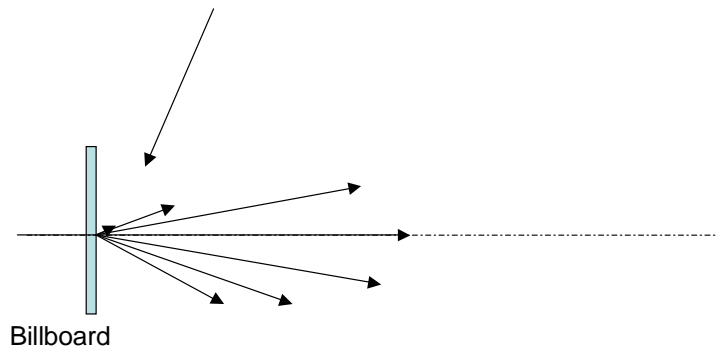
For the digital billboard calculations, it was assumed that no dimming of the light output occurs due to age, as the computerized controls can be set to overcome any LED light output degradation with time. A Light Loss Factor of 0.90 was assumed to account for a possible 10% loss due to the accumulation of dust and dirt.

For the conventional billboard discussed above, a 25% average reflectance was used in the given example. A similar “message” was assumed for the digital billboard calculations, i.e., a billboard luminance was assumed that would be created by an array of colors equivalent to that used for the conventional billboard analysis, rather than an all white display. It was further assumed that a 14 x 48 ft. billboard would be operated at 4.3% of full output at night, as recommended in table 4 above. For these example conditions, the amount of light directly emitted into the atmosphere by the digital billboard is 2260 lumens. This compares to the value of 31,535 sky lumens for the example conventional billboard lighted by four bottom mounted luminaires, and is 8% of that amount.

Digital billboards can be seen to offer a major opportunity to reduce sky glow if they are replacing conventional billboards that employ a bottom mounted lighting system. This is a result of the elimination of the external luminaires and the direct sky lumens they produce, and also because of the design of digital billboards whereby less light from the billboard face is directed upward versus downward.

Ian Lewin Ph.D., FIES, L.C.
November 26, 2008

Effect of Horizontal Louver Blades



Length of Arrows Represent Light Intensity

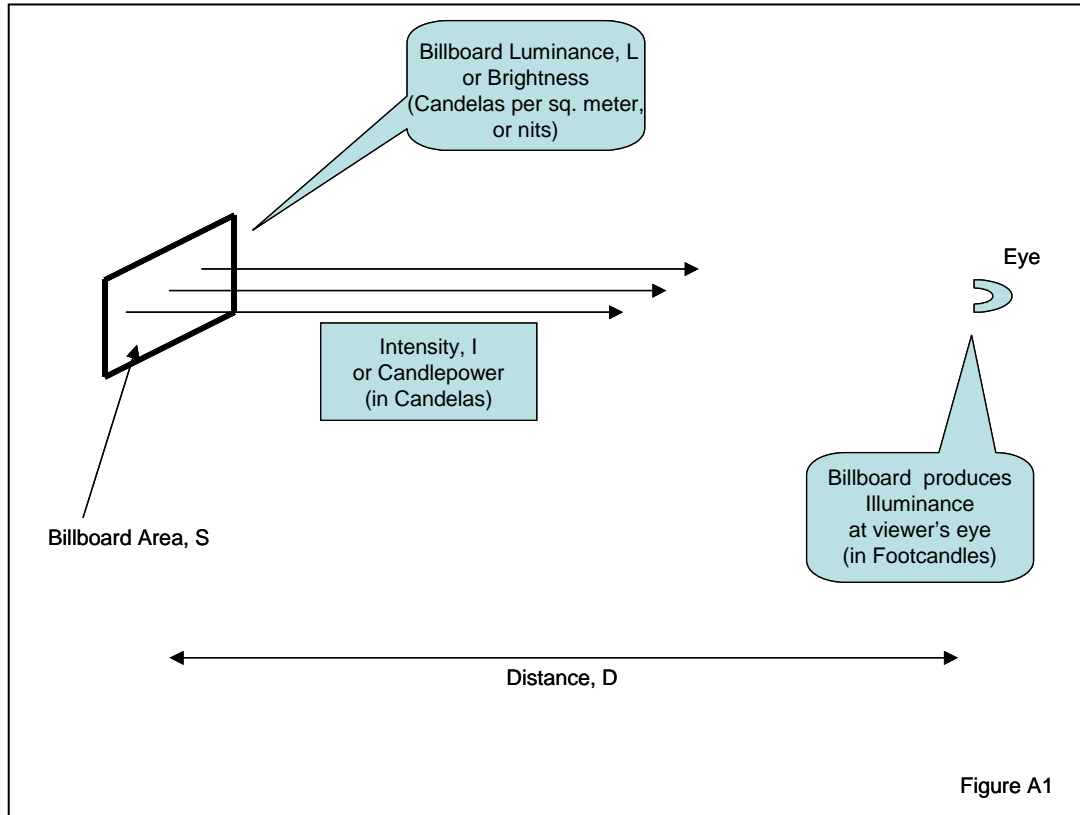
Uplight is Partially Shielded

Figure 1

Appendix A

Lighting Units and Terms

Several terms are useful in describing the light characteristics of digital billboards. See figure A1.



Candlepower. This is the intensity, I , of light produced by the billboard in a particular direction, and it is measured in “candelas.” For example, a billboard of a certain size will emit a certain intensity of light in a direction perpendicular to its face. The intensities emitted in other directions will be less than that in the perpendicular direction. If the billboard displays a white image, this intensity will be higher than if the billboard face is any other color.

Candlepower does not change significantly with distance, providing the atmosphere is clear; the intensity continues as the light rays move in a straight line until they strike a surface.

Luminance, L , often called “brightness,” relates to the overall appearance of the billboard. It is the candlepower emitted per unit area, and is expressed in units of “candelas per square meter,” or $\text{cd}/\text{sq.m}$. Say a billboard that has an area of 2 square meters produces 400 candelas when viewed from a direction perpendicular to its face, then its luminance is $400/2$, equal to 200 $\text{cd}/\text{sq.m}$. The term “nit” is also used. Such a billboard is said to have a brightness of 200 nits.

The formula relating the billboard size, luminance (or brightness) and the candlepower it projects is:

Candlepower (in candelas) = Luminance (in candelas/sq.m. or nits) x billboard area (in square meters)

or
$$I = L \times S \quad \text{_____ A1.}$$

(L is in nits, S is in sq.m.)

Illuminance, E. This is a measure of the amount of light that is intercepted by an object that is illuminated by the billboard. Illuminance is measured in “footcandles,” and is dependent on the distance from the billboard, as well as the candlepower the billboard produces. If a viewer is looking at the billboards, the illuminance at the viewer’s eye, E_v , can be found using the “Inverse Square Law,” which states

$$\text{Illuminance (in footcandles)} = \frac{\text{Candlepower (in candelas)}}{\text{Distance}^2 \text{ (in feet)}}$$

or
$$E_v = \frac{I}{D^2} \quad \text{_____ A2.}$$

The value of I from equation 1 can be substituted into equation 2 to give

$$E_v = \frac{L \times S}{D^2} \quad \text{_____ A3.}$$

Equation 3 is very useful because it relates billboard size (S), billboard luminance (or brightness) (L), and gives the footcandles (E_v) that will be produced by the billboards at a distance, D feet. It can be rewritten:

$$L = \frac{D^2 E_v}{S} \quad \text{_____ A4.}$$

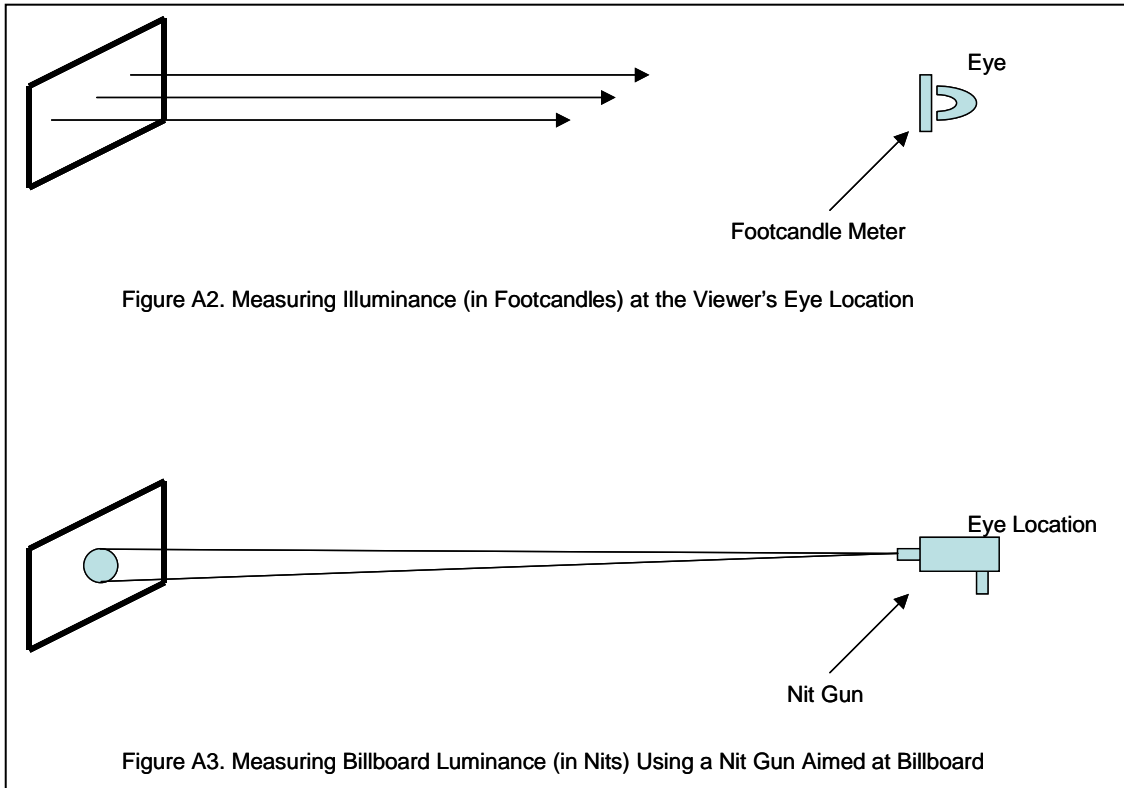
L is in nits, E_v is in footcandles,
D is in feet, S is in sq. meters

Otherwise, if the area of the billboard, S, is in square feet, the equation becomes

$$L = \frac{10.76 D^2 E_v}{S} \quad \text{_____ A5.}$$

L is in nits, E_v is in footcandles,
D is in feet, S is in sq. feet

The illuminance, E, can be measured easily with a relatively inexpensive footcandle meter at a measured distance D feet from the billboard. Figure A2. The area of the billboard, S, presumably is known. Inserting these values of E, D and S into equation 5 allows the luminance, L in nits, to be calculated.



L, the billboard luminance, can also be measured with a “nit gun”, which is a luminance meter that can be pointed at the billboard. Figure A3. However such devices are more expensive and less readily available than a footcandle meter.

Because of the simple relationship as given in equation A5, billboard luminance specifications can be written in terms of footcandle limitations at a certain distance. For compliance checking, if the footcandle value produced by the billboard and measured at a prescribed distance is at or below a specified level, then it will be known that the billboard luminance meets the desired limitation.

Appendix B

Description of the Lighting Environmental Zone (from IESNA publication TM-11-00)

- E1. Areas with intrinsically dark landscapes. Examples are national parks, areas of outstanding natural beauty, or residential areas where inhabitants have expressed a strong desire for strict limitation of light trespass.
- E2. Areas of low ambient brightness. These may be suburban and rural residential areas. Roadways may be lighted to typical residential standards.
- E3. Areas of medium ambient brightness. These will generally be urban residential areas. Roadway lighting will normally be to traffic route standards.
- E4. Areas of high ambient brightness. Normally this category will include dense urban areas with mixed residential and commercial use with a high level of nighttime activity.

Note: The above descriptions are being considered for revision by IESNA at the time of writing this report. The categories are not changed, but the descriptions are more extensive for clarity.