LESS: **L**uminaire **E**valuation and **S**election **S**ystem

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1. INTRODUCTION

This report summarizes and evaluates the existing IESNA outdoor luminaire cutoff classification system. It also proposes a new luminaire evaluation and selection system (LESS) which can be the foundation for new luminaire performance classifications. LESS is based on the quantity of luminous flux emitted by a luminaire into four specified angular regions, termed “forward light”, “backlight”, “high angle light”, and “luminaire uplight”. The luminous flux distributed by the luminaire into each region would be published as a percentage of total lamp lumens. The proposed angular regions and criterion flux values are based on existing recommendations and on the analyses described within this report. Importantly, the angular boundaries and criteria are provided only as a starting point for the IESNA, through the committee process, to reach consensus on these values.

LESS will provide information about the ability of a luminaire to emit light into directions were it is likely to be wanted (“forward light”), as well as how much light is emitted into other directions of concern (e.g., uplight). Further, since the proposed system is based on luminous flux, it is easy to account for all the flux emitted by a lamp and segregate the total flux into meaningful categories for potential applications. Moreover, simple graphics can be used in LESS to easily visualize the segregated flux for one luminaire or to easily compare multiple luminaires.

The new system will afford a useful way for:

- manufacturers to design, test, and report luminaire performance
- designers to more easily select luminaires for outdoor applications
- end users to more easily understand luminaire light distributions

2. BACKGROUND

This section discusses the general goals for outdoor lighting. It defines the existing IESNA outdoor luminaire cutoff classification system and describes some of the limitations of this system in helping lighting designers and specifiers achieve these goals. Additionally, this section discusses ways that LESS can help overcome these limitations.

In designing an outdoor lighting installation, an important goal is to efficiently put light where is should go, and to avoid negative impacts of lighting, such as glare, light trespass or sky glow. A useful preliminary step in the design of outdoor lighting is to narrow down the general type of luminaire planned for use, based on aesthetic characteristics, site geometry, and on the performance characteristics of luminaires. While the characteristics of the luminaire alone will not allow precise prediction of the performance of a specific lighting installation, it is expected that the specifier can make some initial decisions with luminaire-specific performance information.

Currently, outdoor luminaire selection heavily weights the existing IESNA cutoff classification system, sometimes to the exclusion of other considerations. This is evident from the way cutoff is being used as the sole measure of performance for selecting outdoor luminaires in lighting ordinances around North America at the state/provincial and local levels. An erroneous assumption often made about the existing cutoff classification system is that it provides a way to predict a luminaire's potential to cause "light pollution" (e.g., glare, light trespass, and sky glow). In actuality, it provides very little information about the amount or direction of light from a luminaire to directions of concern. Additionally, the existing cutoff classification is silent on a luminaire's potential to produce forward light, which is, after all, the purpose of outdoor lighting. A luminaire evaluation and selection system that provides a complete picture of light into useful directions and into directions of potential concern would be better suited as the main tool for luminaire comparison and selection.

Because the IESNA cutoff classification system has become so important, it is worthwhile to consider how it is defined and how it is being used. The current metric used in the cutoff classification is luminous intensity (cd). The maximum intensity permitted is stipulated as a percentage of the total lamp luminous flux (lm). The definition for each cutoff classification is identical with the exception of the different values for the criteria in two separate angular regions, one between 80^o and 90^o from luminaire nadir and one above 90^o from nadir. For example, in IESNA RP-8-00 (IESNA 2000), the definition for full cutoff requires 0 cd at or above 90^o and requires that the value of maximum intensity (cd) is less than 10% of the value of lamp luminous flux (lm) at or above 80^o, and is given as:

> ***"Full Cutoff****: A luminaire light distribution where zero candela intensity occurs at or above an angle of 90° above nadir. Additionally the candela per 1000 lamp lumens does not numerically exceed 100 (10 percent) at or above a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire."*

The complete definitions for all the cutoff classifications, as well as minor discrepancies found between relevant IESNA documents, are provided in Appendix A.

There are several fundamental questions about the suitability of the existing cutoff classification system to communicate information about a luminaire's light distribution. In addition, there are questions about the usefulness of the angles and the criterion values used in the classifications as they are currently being applied. In terms of a communication tool to impart information about a luminaire's performance, the existing cutoff classification system is confusing and difficult to use (Bullough 2002). Confusion arises because the cutoff classification relates two different quantities to one another: by setting the limit on luminous intensity (cd) as a percentage of lamp luminous flux (lm) for each classification.

Furthermore, the existing cutoff classifications do not separately address high angle light (defined as light within the angular region between 80° and 90° from nadir) and luminaire uplight (defined as light within the angular region at or above 90° from nadir). Useful comparisons of luminaires are difficult due to this combination of two requirements in one classification. Without further information, it is impossible to know whether the high angle light or the luminaire uplight resulted in a particular classification. As an example, a luminaire can be classified as a semicutoff even if it produces no luminaire uplight. In this case the semicutoff classification is a result of the high angle luminous intensity. This is potentially confusing because there is often a presumption that a luminaire emitting no uplight is classified as full cutoff.

In terms of the suitability of the cutoff classification system's angular regions and specified criteria, it is worthwhile to consider whether the cutoff classifications were developed for the purposes for which they are currently being used. The cutoff classification was originally developed only to limit high angle light likely to contribute to glare in roadway lighting (Rex 1960, 1963). Limits on uplight emitted by a luminaire were added later. The existing cutoff classification system is now being used for *all* outdoor lighting applications in the selection process for luminaires. Its effectiveness at predicting a luminaire's performance for applications other than roadway lighting is, at best, questionable. Research shows that the cutoff classification is not an accurate predictor of glare, sky glow, or light trespass (Keith 2003, Laporte and Gillet 2003, McColgan et al. 2004, McColgan and Van Derlofske 2004). Additional discussions on the usefulness of the cutoff classification to predict light trespass, glare, or sky glow are given in Appendix B.

For all of these reasons, a luminaire evaluation and selection system that is intuitive and easy to use is proposed. In developing a system that provides a reliable first-order comparison of luminaires for their suitability for outdoor lighting, one might envision a system that indicates the amount of light into the area likely to be lighted, as well as the amount of light into the areas where light is likely not needed or wanted. Such a system could provide a simple, easy-to-use communication tool to describe a luminaire's light distribution.

3. LESS: LUMINAIRE EVALUATION AND SELECTION SYSTEM

This section describes limitations with current metrics used to select a luminaire for an outdoor application. It also describes LESS and gives an example of how the system might be used. It defines angular regions, criteria, and classifications for forward light, backlight, high angle light, and luminaire uplight. It also provides justification for the selection of these values.

3.1 Proposed Luminaire Evaluation System Description

Currently when a specifier is selecting a luminaire for an exterior lighting application, there is a limited amount of information available about the luminaire's photometric performance to help make preliminary selections. The types of information that are typically available include:

- Luminaire efficiency
- Type classification (indicating the distribution on the ground)
- Cutoff classification

Using these luminaire characteristics to make a selection has limitations. Luminaire efficiency is the luminous flux emitted by a luminaire in all directions, as a percentage of the lamp luminous flux (lm). Because it is not direction-specific, it is impossible to determine the amount of light going to areas of interest from this metric. For example, a luminaire might emit 100% of the lamp luminous flux as luminaire uplight, and thus would have an efficiency of 100%, but certainly would not be very effective in almost any lighting application. The luminaire type classification (e.g., Type I, II, III, etc.) is often based upon simple schematic drawings of the illumination pattern hypothetically produced by luminaires. These are often simplified distributions and are not representative of the actual distribution of light from any specific luminaire. Furthermore, the luminaire lateral distribution type does not provide any indication of how much of the luminaire's total light output is producing that distribution, or in other words, does not provide an indication of the potential application efficiency of the luminaire. This concept is similar to luminaire application efficacy (Rea and Bullough 2001) except that it is not defined with respect to lamp efficacy. Finally, and most importantly, these pieces of information, while of some use when considered separately, together result in an awkward and incomplete system to predict a luminaire's performance for a lighting application.

LESS is presented to address these deficiencies. The proposed system represents an intuitive and comprehensive way of specifying a luminaire's performance. It is based on luminous flux emitted by a luminaire into four angular regions categorized as forward light, backlight, high angle light, and luminaire uplight (Figure 3-1).

To define the angular region for forward light, it makes sense to consider where light is likely to be wanted. The angular region for forward light is defined as the general area toward the front of the luminaire, in the downward direction. Specifically, the angular region for forward light is defined as horizontal angles from -120° to +120° and vertical angles from 0° to 80°.

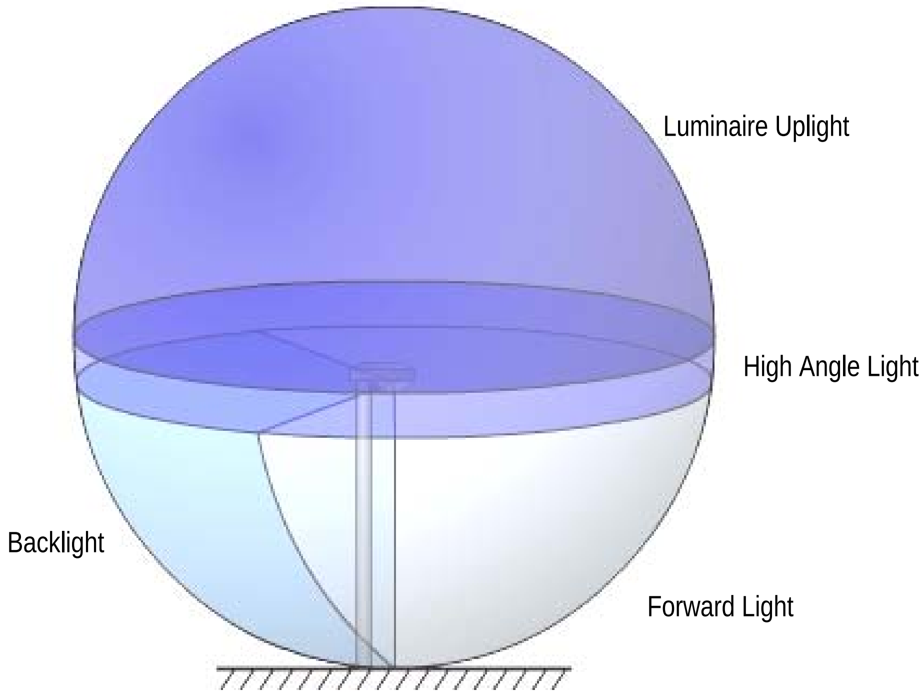


Figure 3-1. Distribution of luminaire luminous flux.

The angular region for backlight is based on angles relating to mounting height distances and the potential impact of backlight at various angles. The angles that define the backlight region include vertical angles from 0° up to 80° from luminaire nadir and horizontal angles from 120° to 240° from the front of the luminaire.

For high angle light, the angular region of interest includes a vertical angular range from 80° up to 90° from nadir. While this angle might not be ideal given recent vehicle windshield designs that permit direct view of luminaires at angles significantly lower than 80° from nadir (Van Derlofske 2004), this angle is currently used in the current IESNA cutoff classification system to define high angle light and is tentatively proposed for use here, subject to change based on input from relevant IESNA committees.

For luminaire uplight, the angular region of interest is above the luminaire. This is defined as all vertical angles at and above 90° from the luminaire nadir.

Light distributed into the four angular regions are related to a luminaire's potential to:

- Light the area of interest
- Cause light trespass
- Cause glare
- Contribute to sky glow

Luminous flux within an angular region (having a specific solid angle) is technically luminous intensity, which is used in the current cutoff classification. However, reporting luminous flux into the proposed angular regions reveals intuitively useful information as to how a luminaire might be expected to perform. Forward light, backlight, high angle light, and luminaire uplight are based on the percentage of lamp lumens emitted by a luminaire into a specified angular region. The sum of the flux from these four regions is equal to the efficiency of the luminaire. Importantly, as illustrated in Figure 3-1, the proposed angular regions encompass the entire distribution of light around the luminaire, so that addition of the luminous flux in the angular regions, plus the light lost inside the luminaire, adds to 100% of the luminous flux emitted by the lamp.

Figure 3-2 shows the luminous flux (as a percentage of lamp luminous flux) from several 150 W metal halide (MH) and high pressure sodium (HPS) decorative luminaires. Each bar represents a luminaire and each pattern within the bar represents the amount of luminous flux emitted into the corresponding angular region, as well as light trapped in the luminaire. For an application requiring no uplight, it is immediately apparent that only luminaire D6 meets that requirement. For an application requiring the least amount of backlight, luminaire D8 meets that requirement as well. For a maximum amount of forward light, luminaire D3 is the appropriate selection. Of interest, the system also provides a means to view backlight as a useful quantity. For example, in an urban downtown area where residents and business owners might welcome light onto their doorsteps, Figure 3-2 illustrates that luminaire D2 has the highest percentage of backlight.

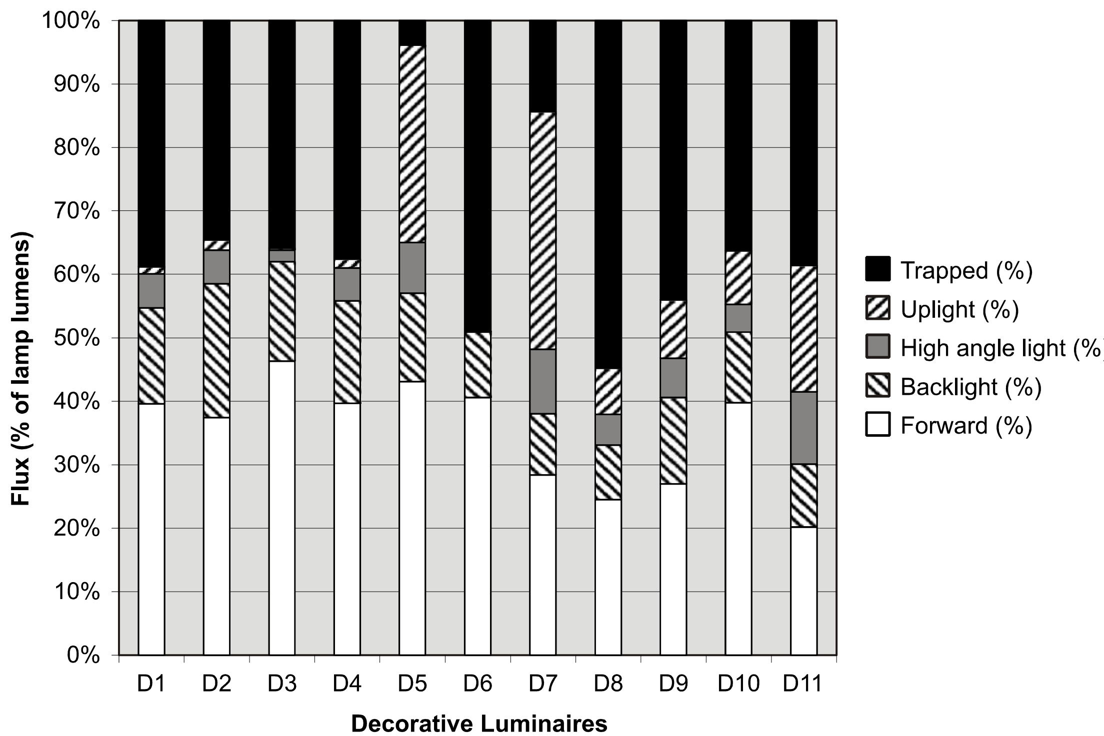


Figure 3-2. Comparison of 150 W MH and HPS decorative luminaires.

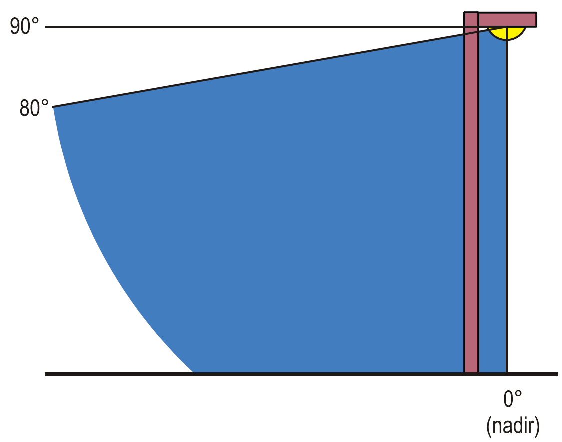
3.2 Angular Regions, Criteria, and Classifications

This section defines the angular regions for each category (backlight, high angle light, and luminaire uplight). It also defines the criterion flux values for each category leading to the interim classifications. A table summarizing the angular regions, criteria, and classifications for each category is also provided. Justification for the choice of the angles for the regions and for the values selected for the criteria is provided in Section 3.3.

It is envisioned that the angular regions and the criteria could be altered for different applications. Rural roadway lighting, urban downtown lighting, parking lot lighting or park pathway lighting may have different angular regions and criteria. The different IESNA committees and relevant IESNA recommended practice documents provide the perfect opportunity to tailor the angular regions and criteria to these applications, and thereby develop classifications for luminaires based upon their potential to meet design objectives.

3.2.1 Backlight Category

Backlight is defined here as the percentage of lamp luminous flux behind a luminaire confined to vertical angles from 0° up to 80° with respect to nadir of the luminaire (Figure 3-3a) and between (and including) the horizontal angles from 120° to 240° from the front of the luminaire (Figure 3-3b).



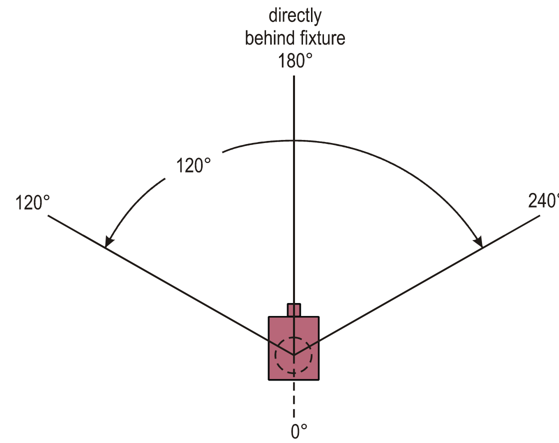


Figure 3-3. Backlight is defined as the percentage of the lamp luminous flux, within (a) vertical angles from 0° up to 80° from nadir, and (b) horizontal angles from 120° to 240° from the front of the luminaire.

Backlight from a luminaire can be further subdivided into three vertical angular zones for classification. All zones include the same horizontal angles (as shown in Figure 3-3b). As illustrated in Figure 3-4, the **vertical** angles of the zones are:

- Zone 1: 0° up to 45° from nadir
- Zone 2: 45° up to 63° from nadir
- Zone 3: 63° up to 80° from nadir

For any luminaire mounted at a height of 8 meters and a home located 8 meters behind a luminaire, no light from Zone 1 would directly fall on the face of the house. Light from Zone 2 would directly fall on the face of the house and, for typical residential home geometry, would probably cover the first story. Light from Zone 3 would also directly fall on the face of the house and would most likely illuminate windows on the second floor.

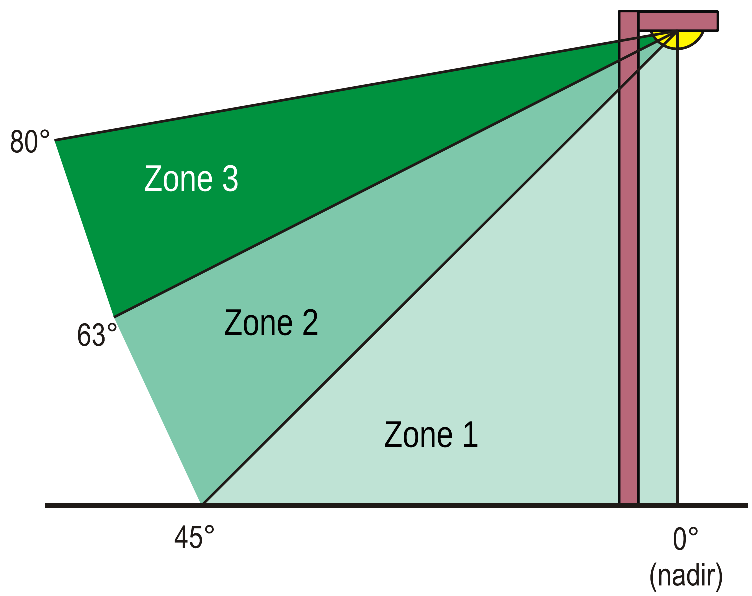


Figure 3-4. Backlight zones within a vertical range of angles based on luminaire mounting height.

The proposed backlight classification has two numbers. The first number is the total backlight as a percentage of the lamp luminous flux. The second number is the zone containing the maximum luminous flux of the three zones.

The proposed backlight classifications and criteria are:

- B [Total Luminous Flux]-Z1: Maximum flux in Zone 1
- B [Total Luminous Flux]-Z2: Maximum flux in Zone 2
- B [Total Luminous Flux]-Z3: Maximum flux in Zone 3

For example, consider the backlight classification of representative luminaires in Table 3-1. An analysis of these and other lighting products using the proposed luminaire performance specification system is presented in more detail in Section 4. These luminaires are representative of the products that were used in the analysis. For the purposes of this report, functional luminaires are defined as luminaires typically used in applications such as parking lots, area lighting and roadway lighting, and include cobra head luminaires, arm mount luminaires, and post-top luminaires. Decorative luminaires include teardrop, pendant, and lantern style luminaires. The functional luminaires labeled F5 and F10 are both 250 W MH luminaires with Type III distributions. The decorative luminaires labeled D2 and D8 are both 150 W HPS Type IV luminaires. In this table, luminaire F5 has the least amount of backlight at 8% and Zone 1 has more flux than Zone 2 or Zone 3, thus the classification B8-Z1. The current IESNA cutoff classifications for these luminaires are also provided for comparison. Both the F10 and D2 luminaires have very different backlight values, even though both are classified as semicutoff under the existing classification system. Luminaire D2 has more total backlight with the largest amount in Zone 3, as compared with luminaire D8 with a maximum luminous flux in Zone 2. However, D2 and D8 are classified as semicutoff and noncutoff, respectively, under the existing IESNA cutoff classification system. Both luminaires F5 and F10 have similar total backlight values and have most of the backlight in Zone 1 but very different classifications under the existing cutoff classification.

Table 3-1. Backlight classification calculated for several representative functional and decorative luminaires.

Vertical Angular Zones	Backlight (% of lamp lumens)			
Luminaire	F5	F10	D2	D8
Zone 1 (0° to 45°)	3.2	4.9	4.5	2.8
Zone 2 (45° to 63°)	2.9	3.6	7.7	3.4
Zone 3 (63° to 80°)	1.6	3.0	8.9	2.4
Total backlight	7.7	11.4	21.1	8.6
Backlight classification	B8-Z1	B11-Z1	B21-Z3	B9-Z2
Current cutoff classification	Full cutoff	Semicutoff	Semicutoff	Noncutoff

Note that there exists the possibility of having a luminaire with a luminous intensity distribution producing no luminous flux at all in Zones 1, 2 or 3. While this possibility is remote, such a luminaire could be classified as B0-Z0.

3.2.2 High Angle Light Category

High angle light is defined as the percentage of the lamp luminous flux emitted by the luminaire into all horizontal angles between the vertical angles of 80° up to 90° with respect to nadir (Figure 3-5).

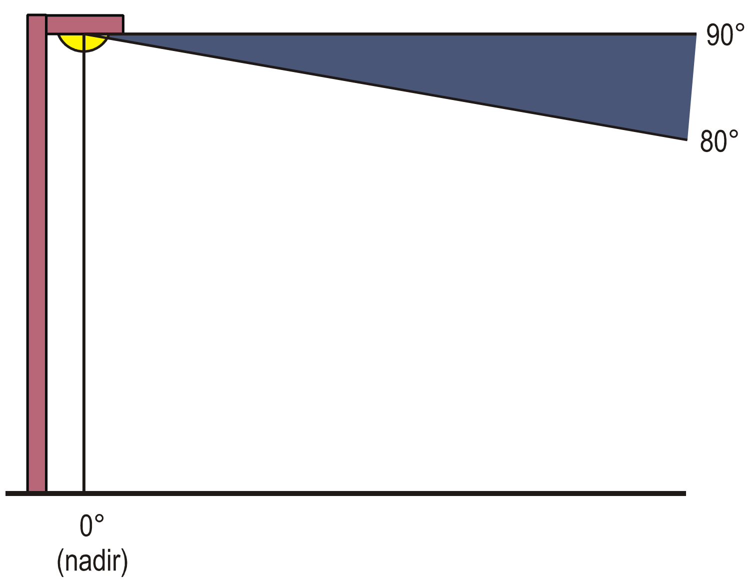


Figure 3-5. High angle light is defined as the percentage of the lamp luminous flux emitted by the luminaire for vertical angles between 80° up to 90° for all horizontal angles about the luminaire.

The proposed high angle light classifications and criteria are:

- HA0: Luminous Flux = 0
- HA1: Luminous Flux < 1%

- HA2: Luminous Flux < 5%
- HA3: Luminous Flux < 11%
- HA4: Luminous Flux ≥ 11%

where the luminous flux is a percentage of the lamp luminous flux for vertical angles from 80° to 90°.

For example, consider the high angle light of the representative luminaires in Table 3-2. An analysis of lighting products using the proposed luminaire performance system is given in Section 4. These luminaires are representative of the products that were used in the analysis. The functional luminaires labeled F5 and F10 are 250 W MH luminaires with Type III and Type II distributions, respectively. The decorative luminaires labeled D2 and D8 are 150 W HPS Type IV luminaires. The high angle light for the proposed classifications range from HA1 (<1%) to HA3 (<11%). The current IESNA cutoff classifications for these luminaires are also provided for comparison. The F10 and D2 luminaires have very different high angle light values, but are both classified as semicutoff under the existing IESNA cutoff classification system. Under the proposed system, luminaire D8 has a high angle light classification of HA2 (<5%) while luminaire D2 has a high angle light classification of HA3 (<11%). Under the existing cutoff classification system, luminaires D2 and D8 have classifications of semicutoff and noncutoff, respectively.

Table 3-2. High angle light classification calculated for several representative functional and decorative luminaires.

Luminaire	High Angle Light (% of lamp lumens)	High Angle Flux Classification	Current Cutoff Classification
F5	0.4	HA1	Full cutoff
F10	0.4	HA1	Semicutoff
D2	5.3	HA3	Semicutoff
D8	4.8	HA2	Noncutoff

3.2.3 Luminaire Uplight Category

Luminaire uplight is defined as the percentage of lamp luminous flux emitted above a luminaire. As shown in Figure 3-6, all of the luminous flux emitted at or above a vertical angle of 90° from nadir is luminaire uplight.

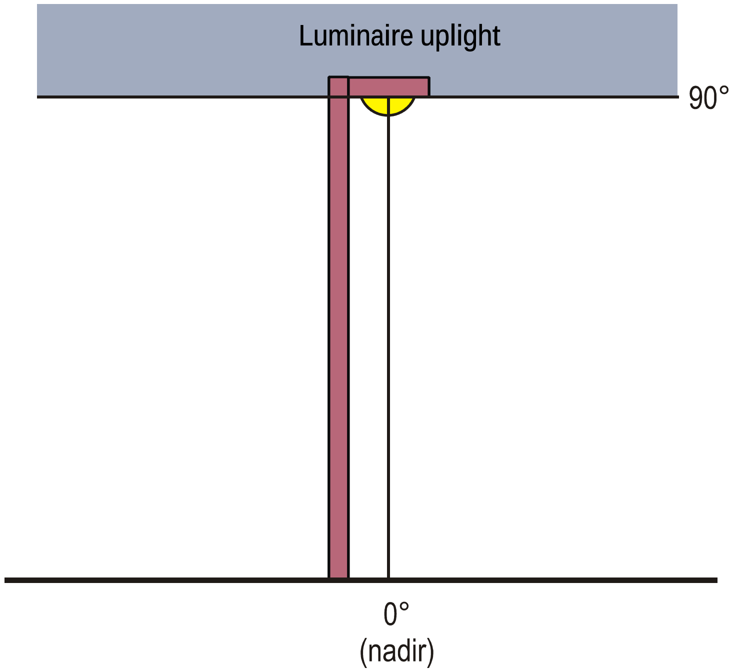


Figure 3-6. Luminaire uplight is the percentage of lamp luminous flux emitted by a luminaire at or above a vertical angle of 90° from nadir.

The proposed luminaire uplight classifications and criteria are:

- U0: Luminous Flux = 0%
- U1: Luminous Flux < 3%
- U2: Luminous Flux < 9%
- U3: Luminous Flux < 15%
- U4: Luminous Flux ≥ 15%

where the luminous flux is a percentage of the lamp luminous flux for vertical angles equal to or greater than 90°.

For example, consider the luminaire uplight of the luminaires in Table 3-3. An analysis of lighting products using the proposed luminaire performance system is given in Section 4. These luminaires are representative of the products that were used in the analysis. The functional luminaires labeled F5 and F10 are both 250 W MH luminaires with Type III and Type II distributions, respectively. The decorative luminaires labeled D2 and D8 are both 150 W HPS type IV luminaires. The luminaire uplight classifications range from U0 (0%) to U2 (9%). The current IESNA cutoff classifications for these luminaires are also provided for comparison. Luminaire F10 has a classification of U0 (0%) under the proposed system. Under the existing IESNA cutoff classification system, F10 is classified as semicutoff.

Table 3-3. Luminaire uplight classification calculated for several representative functional and decorative luminaires.

Luminaire	Luminaire Uplight (% of lamp lumens)	Luminaire Uplight Classification	Current Cutoff Classification
F5	0	U0	Full cutoff
F10	0	U0	Semicutoff
D2	1.6	U1	Semicutoff
D8	7.3	U2	Noncutoff

3.2.4 Angular Regions, Criteria, and Classification Summary

The definitions of the regions and the classifications associated with backlight, high angle light, and luminaire uplight are summarized in Table 3-4.

Table 3-4. Summary of categories, angular regions and zones, criteria, and classifications.

Category	Definition (% of lamp luminous flux)	Classifications
Backlight	Flux behind luminaire in a horizontal angular range from 120° to 240° and in a vertical range from 0° to 80°. The vertical angular range is further broken down into three zones: Zone 1: 0° to 45° Zone 2: 45° to 63° Zone 3: 63° to 80°	B [Total Luminous Flux]-Z1: Maximum luminous flux in Zone 1 B [Total Luminous Flux]-Z2: Maximum luminous flux in Zone 2 B [Total Luminous Flux]-Z3: Maximum luminous flux in Zone 3
High Angle Light	Flux for vertical angles, $80° \leq \theta \leq 90°$	HA0: Luminous Flux = 0% HA1: Luminous Flux < 1% HA2: Luminous Flux < 5% HA3: Luminous Flux < 11% HA4: Luminous Flux ≥ 11%
Luminaire Uplight	Flux for vertical angles, $\theta \geq 90°$	U0: Luminous Flux = 0 U1: Luminous Flux < 3% U2: Luminous Flux < 9% U3: Luminous Flux < 15% U4: Luminous Flux ≥ 15%

3.3 Justification for the Proposed System

This section provides justification for LESS and describes in detail the rationale for the angular values and criteria used.

3.3.1 Luminaire Evaluation and Selection System

This section describes the justification of the proposed system as a simple, easy-to-use communication device to impart useful information intuitively about a luminaire's performance. It describes the reasoning behind the decision to move from a luminous intensity-based metric to a luminous flux-based metric, as well as why this metric is well-suited to indicate luminaire performance. The fact that the classification system provides a means to examine the amount of light into different angular regions for one luminaire as well as to compare the light into different angular regions for multiple luminaires is discussed. Finally the advantages of including forward light to describe the flux distribution of the luminaire are explained.

LESS provides a much more comprehensive picture of where the light from a luminaire is going than does the current IESNA cutoff classification system. The proposed system not only allows for a comparison with respect to where light is not wanted, but also provides information about the direction and quantity of forward light. All of this information can be presented together graphically as a communication tool. It can provide a simple, effective way to understand the distribution of a single luminaire and also to compare multiple luminaires and make informed preliminary selections.

In comparison, the current cutoff classification system does not provide a comprehensive picture of the performance of a luminaire. Using maximum luminous intensity within a particular angular region of interest (such as luminaire uplight) is not indicative of the total amount of light being distributed into that region. For example, if for one luminaire, the luminous intensity in the luminaire uplight region is 50 cd in one particular direction but nearly 0 cd in all other upward directions, very little luminous flux is actually emitted upward. A second luminaire could have a luminous intensity of 49 cd in all upward directions and would therefore have a much larger quantity of light emitting upward, even though the maximum luminous intensity above 90° from nadir is lower than that of the first luminaire.

The spirit of the current cutoff classification system is to provide a meaningful comparison of luminaires with respect to the direction and quantity of light produced in certain angular regions. This spirit is preserved in LESS, since luminous flux within a specified region is analogous to the average luminous intensity within that angular region. The quantity of luminous flux into a specified angular region provides a useful communication device that can help lead to more efficient outdoor lighting applications because the distribution of light from a luminaire, both where it is and is not likely to be wanted, is quickly and effectively understood by specifiers. Of course, once the complete geometry including luminaire layout for a specific installation is known, the effectiveness of the luminaire to light the area of interest and minimize light trespass, glare, and sky glow will still be determined directly from the luminaire’s luminous intensity distribution. The proposed system is a means for initial comparison of luminaires only.

The existing cutoff classification is silent with respect to “forward” light. By selecting angular regions that include the “forward” region, comparisons are allowed based upon forward light, not only backlight, high angle light, or luminaire uplight (where it is less likely to be useful). The graph in Figure 3-2 shows that a specifier can make decisions based on both forward light and light in other angular regions. For example, both luminaires D5 and D7 have approximately equal amounts of backlight, high angle light, and luminaire uplight, but luminaire D5 has more forward light.

The use of luminous flux quantities for each angular region (including the “forward” region) is such that the sum of the luminous flux in all the angular regions together equals the entire amount of luminous flux produced by the luminaire. (The remaining luminous flux is trapped by the luminaire.) Therefore, it naturally lends itself to a comparison of the amount of light emitted by a luminaire into different angular regions. It also provides a simple means for comparing the overall performance of multiple luminaires, simplifying the luminaire selection process.

3.3.2 Flux Categories

The angles selected for the angular regions and the criteria chosen for each classification are provided as a starting point for discussion. It is expected that these tentative values will be modified and refined through input and discussions within the relevant IESNA committees.

3.3.2.1 Backlight

The vertical angular range proposed for backlight is 0^{o} up to 80^{o} from luminaire nadir. This range coincides with distances behind a luminaire. The angles for the backlight zones relate to distances behind a luminaire in terms of mounting height (MH) as shown in Table 3-5.

Table 3-5. Angles used in backlight zones corresponding to distance behind a luminaire.

Zone	Angles (from nadir)	Distance behind luminaire
1	$0° \leq \theta \leq 45°$	Up to 1 MH
2	$45° \leq \theta \leq 63°$	1 to 2 MH
3	$63° \leq \theta \leq 80°$	2 to 6 MH

Although different horizontal angular ranges may be selected to define backlight, a horizontal angular range from 120° to 240° was selected for a number of reasons. Analysis of average luminaire backlight showed that significant amounts of backlight are emitted into angles other than directly behind the luminaire (180^{o} from the front of the luminaire). The analysis showed that the amount of flux increased with an increase in angular range behind the luminaire. However, there are reasons to limit the horizontal angular range behind the luminaire for backlight. Light emitted by the luminaire at angles less than 120° or greater than 240°from the back of the luminaire may include potentially useful light behind the luminaire that could light sidewalks, for example, or provide peripheral visibility to drivers (e.g., Akashi and Rea 2002).

Luminous flux criteria are not proposed for the backlight classifications. There are two reasons for this. First, there are many instances where backlight from a luminaire might be desirable. Second, luminaires are not typically designed to minimize backlight as a method to address light trespass (except for a few luminaires specific to roadways and parking lots). Therefore, the proposed metric includes the total backlight (as a percentage of lamp luminous flux). If luminaire design develops to address backlight, it may be appropriate to change the backlight classification to meet defined criteria.

3.3.2.2 High Angle Light

The vertical angular range proposed for high angle light is 80^{o} up to 90^{o} from luminaire nadir. This range coincides with the angular range for high angle light in the current IESNA cutoff classifications. This angular range may not be appropriate given new vehicle windshield designs that permit direct view of luminaires at angles significantly lower than 80^{o} from nadir (Van Derlofske 2004), but historically this angular range has been found useful for controlling glare.

The luminous flux criteria proposed for the high angle light classifications are based on the current IESNA cutoff classification system and on an analysis of existing lighting products. Table B-1 is reprinted from *NLPIP Lighting Answers: Light Pollution* (McColgan 2003). It provides the range of luminous flux values (as a percentage of lamp luminous flux) allowed from 80° to 90°, calculated for each cutoff classification. Because of the promulgation of lighting ordinances requiring full cutoff luminaires, it is assumed that full cutoff luminaires are considered satisfactory for the level of glare people are willing to accept. Full cutoff luminaires can have a maximum of 11% of the total lamp luminous flux in the high angle light region. Therefore, 11% was chosen as the maximum luminous flux criteria for the high angle light classifications.

An analysis of representative outdoor lighting products was performed to determine the amount of flux emitted into the high angle light region (see Section 4 for further details).

The results of this analysis show that the luminous flux of these luminaires in the high angle light region is significantly lower than 11%. Many of the functional luminaires have high angle light values below 1% of the lamp luminous flux. All of the functional luminaires have high angle light values below 5%. Therefore, a total of five high angle light classifications are proposed, HA0 – HA4, corresponding to maximum luminous flux criteria of 0%, 1%, 5%, 11%, and greater than 11%, respectively.

3.3.2.3 Luminaire Uplight

The vertical angular range proposed for luminaire uplight is all angles at or above 90^{o}. This range coincides with the current cutoff classifications and with the CIE definition of upward light output ratio (ULOR) (CIE 1997). Historically this angular range has been found sufficient and is proposed for use in the luminaire performance system.

The luminous flux criteria proposed for the luminaire uplight classifications are based on the values given in CIE 126-1997 *Guidelines for Minimizing Sky Glow* for various environmental zones (CIE 1997). The range of values given in CIE 126-1997 for various environmental zones is relative to the luminaire luminous flux ($ULOR_{inst}$), not the lamp luminous flux. To relate the CIE recommended $ULOR_{inst}$ values to lamp luminous flux, an assumption must be made regarding the luminaire efficiency. In this proposal, a luminaire efficiency of 60% is assumed. This accounts for the differences between the $ULOR_{inst}$ values and the luminaire uplight criteria proposed here. As in CIE 126-1997, a total of five luminaire uplight classifications are proposed, U0 – U4, corresponding to maximum luminous flux (as a percentage of lamp lumens) criteria of 0%, 3%, 9%, 15%, and greater than 15%, respectively.

4. PRODUCT EVALUATION

An important consideration in assessing the value of LESS is whether it can be applied to existing products. To this end, a number of lighting products were evaluated using the proposed system. Analyses were performed on a sample of functional and decorative luminaires to determine the average values and ranges of luminous flux in each angular region. Analyses were also performed to determine the number of luminaires that fell into each classification for backlight, high angle light, and luminaire uplight. Some luminaires were compared to provide examples of how specifiers might use the proposed system.

Analyses were performed on the luminaires tested in the *NLPIP Specifier Report: Parking Lot and Area Luminaires*. Photometric values for each of these luminaires were measured by an independent laboratory. This database provides a valuable resource for describing the performance of outdoor lighting products. These luminaires are luminaires typically used in applications such as parking lots, area lighting and roadway lighting, and include cobra head luminaires, arm mount luminaires, and post-top luminaires. In this report these luminaires are termed “functional.” These luminaires are all 250 W MH luminaires with lateral distributions from Type I to Type IV with the majority having a Type III distribution, representing a range of products used in North America. The luminaires include products from all four existing cutoff classifications.

Decorative luminaires, including teardrop, pendant, and lantern style luminaires, were also used in the analyses of the proposed luminaire evaluation and selection system. Forty decorative luminaires were evaluated. These luminaires ranged from 100 to 250 W HPS and MH lamps with lateral distributions ranging from Type II to Type V. luminaires include products from all four existing cutoff classifications.

The percentage of luminous flux in each of the defined angular regions was calculated using zonal luminous flux transfer calculations based on the luminous intensity data in the photometric files for all of the luminaires. Only luminaires with complete photometric data were used in the analysis.

For the case of luminaire uplight, 190 photometric files were used for the evaluation (150 functional and 40 decorative luminaires). The luminaire lamp wattages in the luminaire uplight analysis range from 70 to 400 W and the lateral distribution classifications range from Type I to Type V.

4.1 Backlight

Total backlight (as defined in Section 3 of this report) was calculated for several functional and decorative luminaires. The results were further broken down to determine the percentage of backlight into three vertical angular zones. All zones include the same horizontal angles (as shown in Figure 3-3b).

The results are shown in Figure 4-1 and listed in Table 4-1. The average total backlight is approximately 15% as can be seen in the leftmost column. The remaining columns show the average values for the luminous flux in the three zones. The results show that on average, for functional luminaires, backlight is highest in Zone 1 and decreases in Zone 2 and Zone 3. The vertical bars in Figure 4-1 represent the maximum and minimum values for each zone.

Of the 30 functional luminaires, 26 have the maximum luminous flux in Zone 1, 4 have the maximum luminous flux in Zone 2, and there were no luminaires with a maximum luminous flux in Zone 3.

Backlight was also calculated for the decorative luminaires. The results are shown in Figure 4-2 and listed in Table 4-1. The average total backlight for luminaires is approximately 14%. Table 4-2 also shows the average values for the luminous flux in those zones. The results show that on average, that backlight is highest in Zone 2 and lower in Zones 1 and 3. The vertical bars represent the maximum and minimum values of luminous flux in each zone. Of the 40 tested luminaires, seven have the maximum percentage of luminous flux in Zone 1, 28 have the maximum percentage of luminous flux in Zone 2, and five have the maximum percentage of luminous flux in Zone 3.

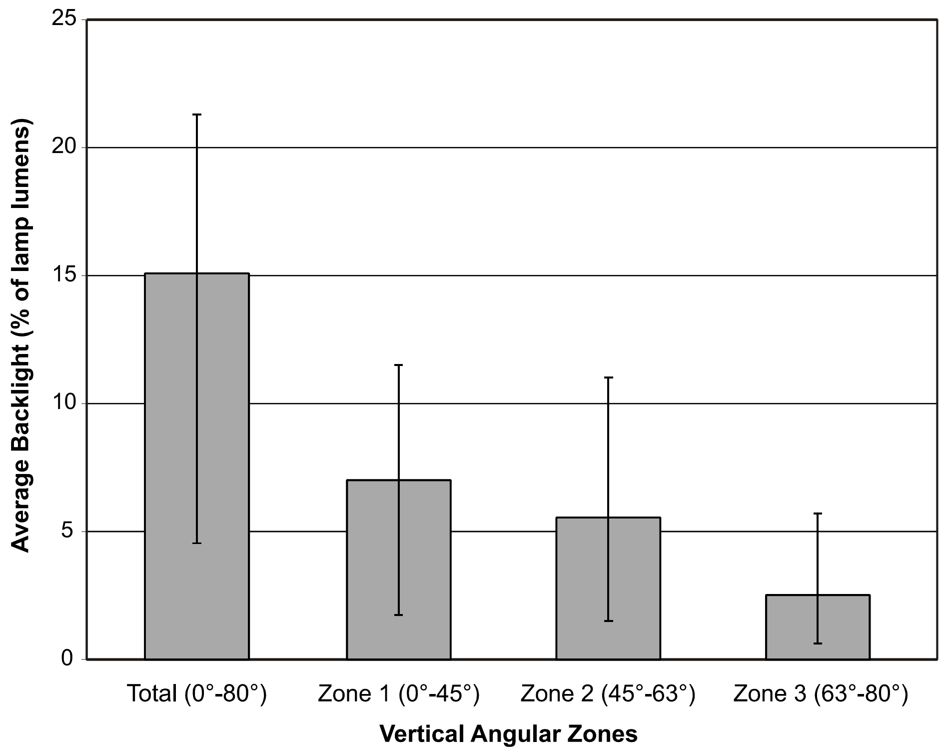


Figure 4-1. Average and range of backlight for the functional luminaires. The vertical bars represent the maximum and minimum values of luminous flux in each zone.

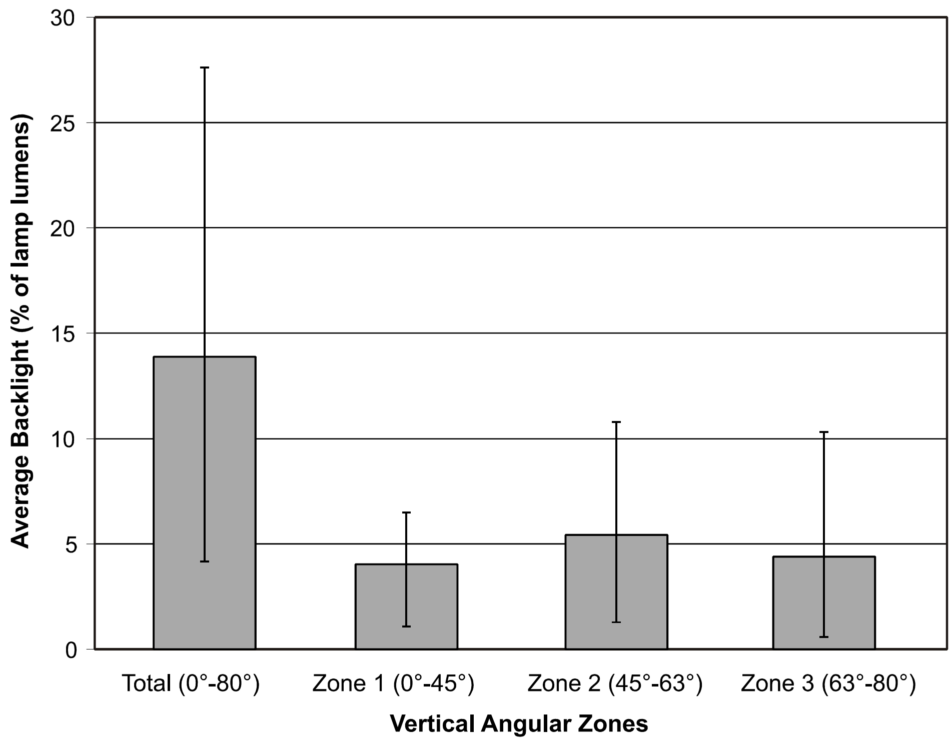


Figure 4-2. Average and range of backlight for the decorative luminaires. The vertical bars represent the maximum and minimum values of luminous flux in each zone.

Table 4-1. Summary of backlight for functional and decorative luminaires.

Luminaire	Backlight (% of lamp luminous flux)							
	Total		Zone 1		Zone 2		Zone 3	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Functional	15.1	4.6 - 21.3	4.0	1.7 - 11.5	5.6	1.5 - 11.0	2.5	0.6 - 5.7
Decorative	13.9	4.0 - 27.6	4.0	1.1 - 6.5	5.4	1.3 - 10.8	4.4	0.6 - 10.3

4.2 High Angle Light

High angle light (as defined in Section 3) was calculated for the functional and decorative luminaires. The results are shown in Figure 4-3 and listed in Table 4-2. The results show that on average, high angle light is higher for decorative luminaires than for the functional luminaires that were evaluated. The vertical bars represent the maximum and minimum values for each type of luminaire. The range of high angle values is larger for decorative luminaires.

The 30 functional luminaires are classified as follows: three are HA0, 20 are HA1, seven are HA2, and none are HA3 or HA4.

The 40 decorative luminaires are classified as follows: none are HA0, seven are HA1, 23 are HA2, nine are HA3, and one is HA4.

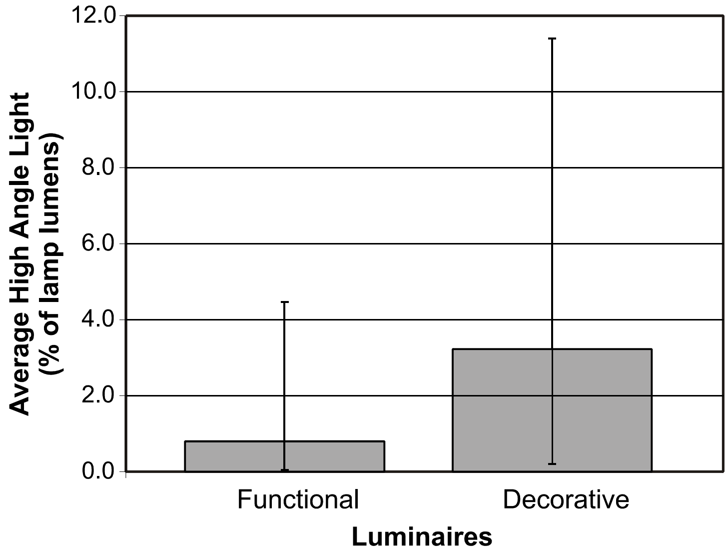


Figure 4-3. Average and range of high angle light for functional and decorative luminaires.

Table 4-2. Summary of high angle light for functional and decorative luminaires.

Luminaires	Average High Angle Light (% of lamp luminous flux)	High Angle Light Range (% of lamp luminous flux)
Functional	0.8	0 - 4.5
Decorative	3.2	0.2 - 11.4

4.3 Luminaire Uplight

Luminaire uplight (as defined in Section 3) was calculated for the functional and decorative luminaires. The results are shown in Figure 4-4 and listed in Table 4-3. The results show that on average, luminaire uplight is higher for decorative luminaires than for functional luminaires. The vertical bars represent the maximum and minimum values for each type of luminaire. The range of luminaire uplight values is large for decorative luminaires and relatively small for functional luminaires.

The 190 luminaires are classified as follows: 40% are U0, 44% are U1, 11% are U2, 1% are U3 and 4% are U4, as shown in the first column in the graph in Figure 4-5. Figure 4-5 shows that the functional luminaires emit less luminaire uplight than the decorative luminaires. Approximately half of the functional luminaires have a luminaire uplight classification of U0.

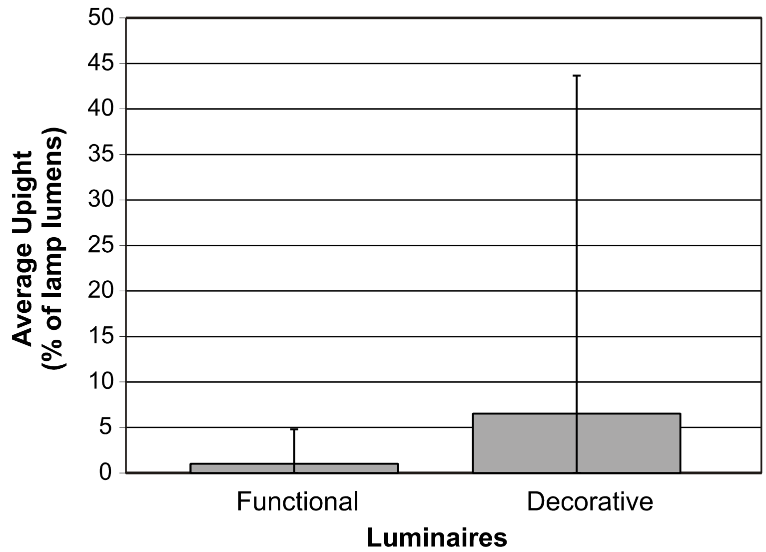


Figure 4-4. Average and range of luminaire uplight for functional and decorative luminaires.

Table 4-3. Summary of luminaire uplight for functional and decorative luminaires.

Luminaires	Average Luminaire Uplight (% of lamp lumens)	Luminaire Uplight Range (% of lamp lumens)
Functional	1.0	0.0 - 4.8
Decorative	6.5	0.0 - 43.7

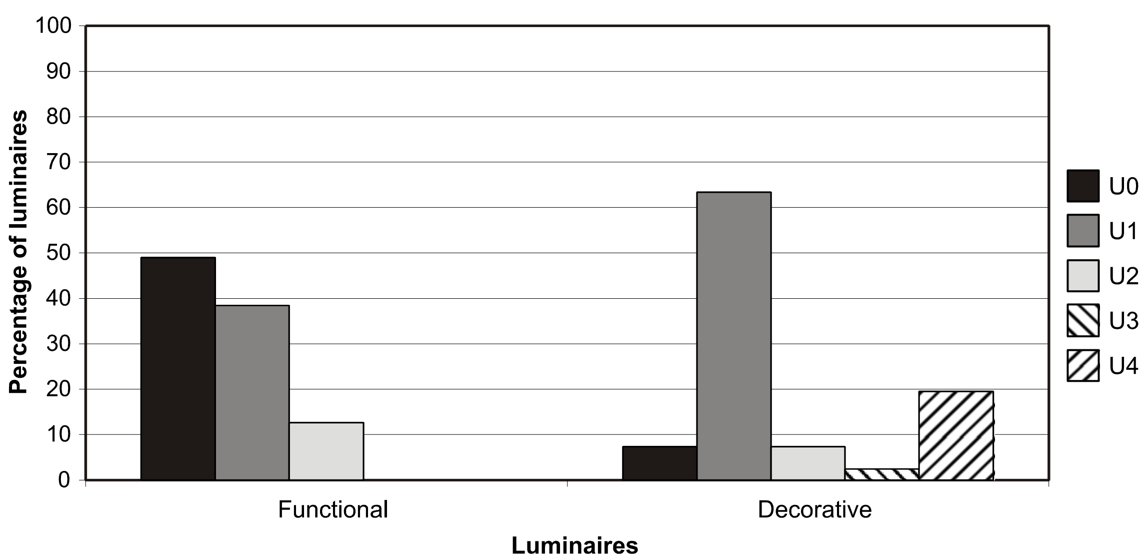


Figure 4-5. Percentage of luminaires in each luminaire uplight classification.

4.4 Using LESS

While the classifications associated with backlight, high angle light, and luminaire uplight each provide useful information, they also comprise a useful communication tool that can be illustrated graphically to provide users with a visual comparison of where the light from a luminaire is going, including forward light. In comparison, the current IESNA cutoff classification system provides no information about the amount of forward light.

4.4.1 Comparisons Among Luminaires

Figure 4-6 shows the flux distribution for ten functional luminaires. Each of these luminaires uses a 250 W MH lamp. The classifications for these ten luminaires are given in Table 4-4.

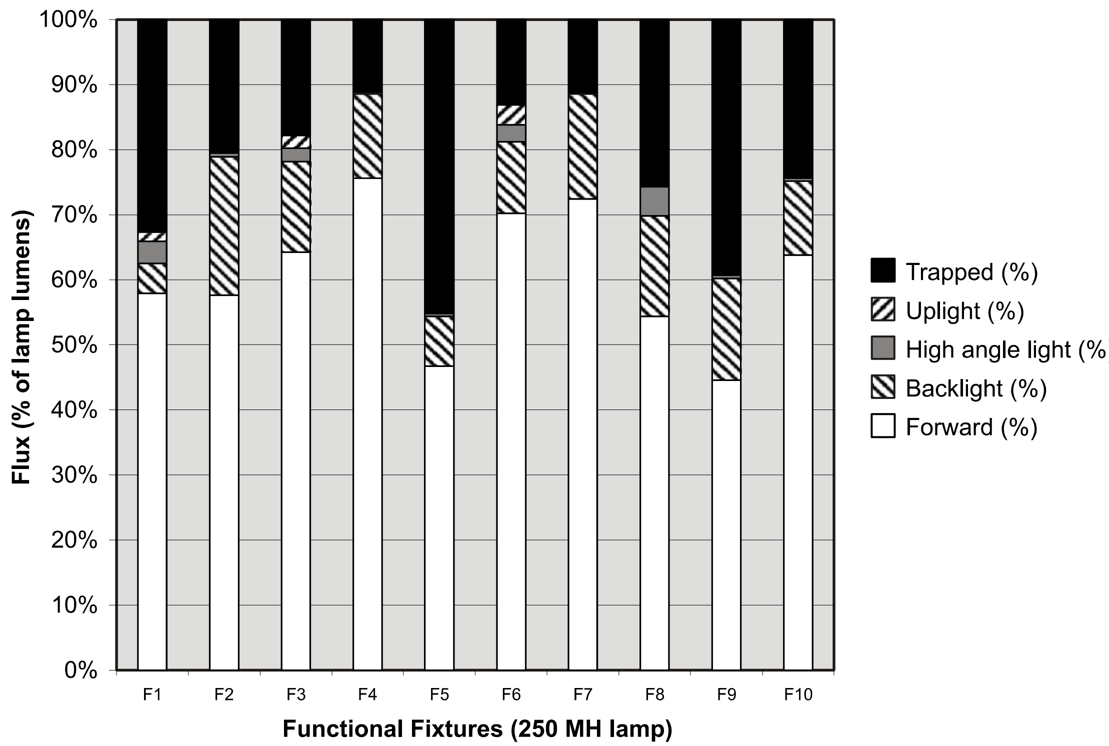


Figure 4-6. Comparison of ten 250 W MH functional luminaires.

Table 4-4. Luminaire classifications for the luminaires in Figure 4-6.

Luminaire	Luminaire Classification		
	Backlight	High Angle Light	Luminaire Uplight
F1	B5-Z1	HA2	U1
F2	B21-Z1	HA1	U0
F3	B14-Z1	HA2	U1
F4	B13-Z1	HA0	U0
F5	B8-Z1	HA1	U0
F6	B11-Z1	HA2	U2
F7	B16-Z1	HA1	U0
F8	B15-Z1	HA2	U1
F9	B16-Z2	HA1	U0
F10	B11-Z1	HA1	U0

A specifier could easily use LESS along with the luminaire light distribution classification system (i.e. Medium, Type III) to select a luminaire for a roadway or parking lot application. For example, in an application requiring no luminaire uplight and little to no high angle light, the specifier might choose among luminaires, F4, F5, F7, or F9. The specifier might further choose F4 due to its high amount of forward light, or F5 if backlight is a concern, because of its low amount of luminous flux in the backlight region.

If the location of the backlight is an important consideration, a specifier may want to compare the backlight for these four luminaires. From Table 4-4, three of these luminaires have a Z1 classification and one has a Z2 classification. The specifier could then evaluate the percentage of backlight in each zone for the luminaires as shown in Figure 4-7. Luminaire F5 has the least amount of total backlight, while F4 and F7 have the lowest amounts of luminous flux in Zone 3.

In LESS, all of this information is readily available to the specifier.

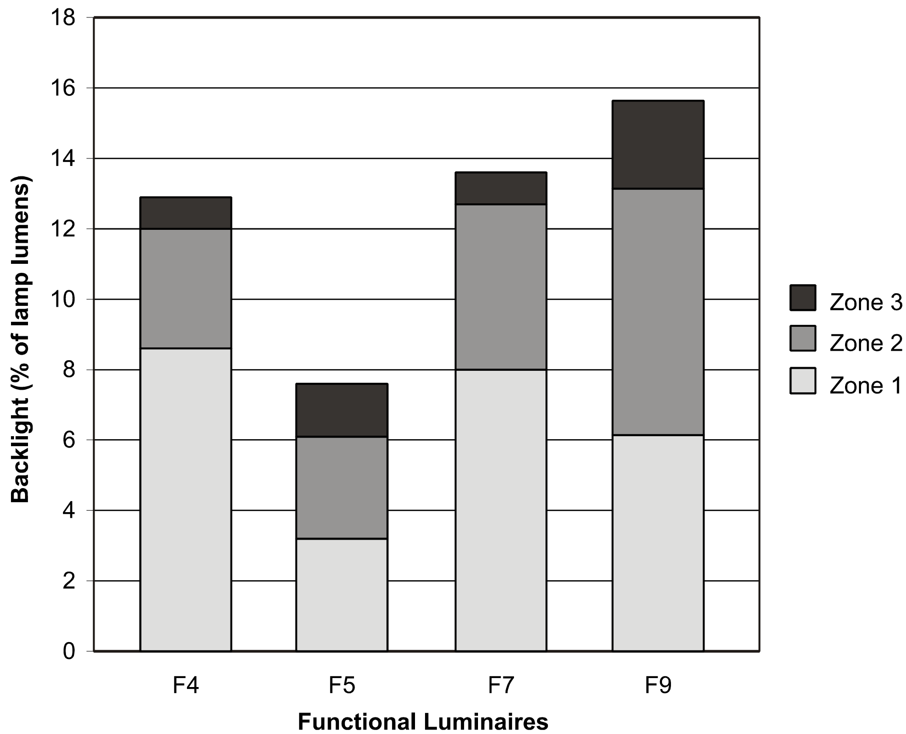


Figure 4-7. Backlight zone comparison for functional luminaires.

A similar type of analysis may be performed with decorative luminaires. The luminaires shown in Figure 4-8 and Table 4-5 use 150 W MH and HPS sources. The lamp lumen output for these lamps is slightly different (MH: 14,000 lumens; HPS: 16,000), but is assumed to be equivalent for the purpose of this comparison. Decorative luminaire selections may be made based on the application and needs of the specifier. If luminaire uplight is an important consideration, Figure 4-8 shows that luminaires D5, D7, and D11 have high luminaire uplight values. Six of the 11 luminaires emit more than 5% of the lamp luminous flux as luminaire uplight. The other five luminaires have lower luminaire uplight values. If high angle light and backlight are also important considerations, luminaire D6 has very low luminaire uplight and low high angle light and has the majority of its backlight in Zone 1 as shown by its luminaire performance classification.

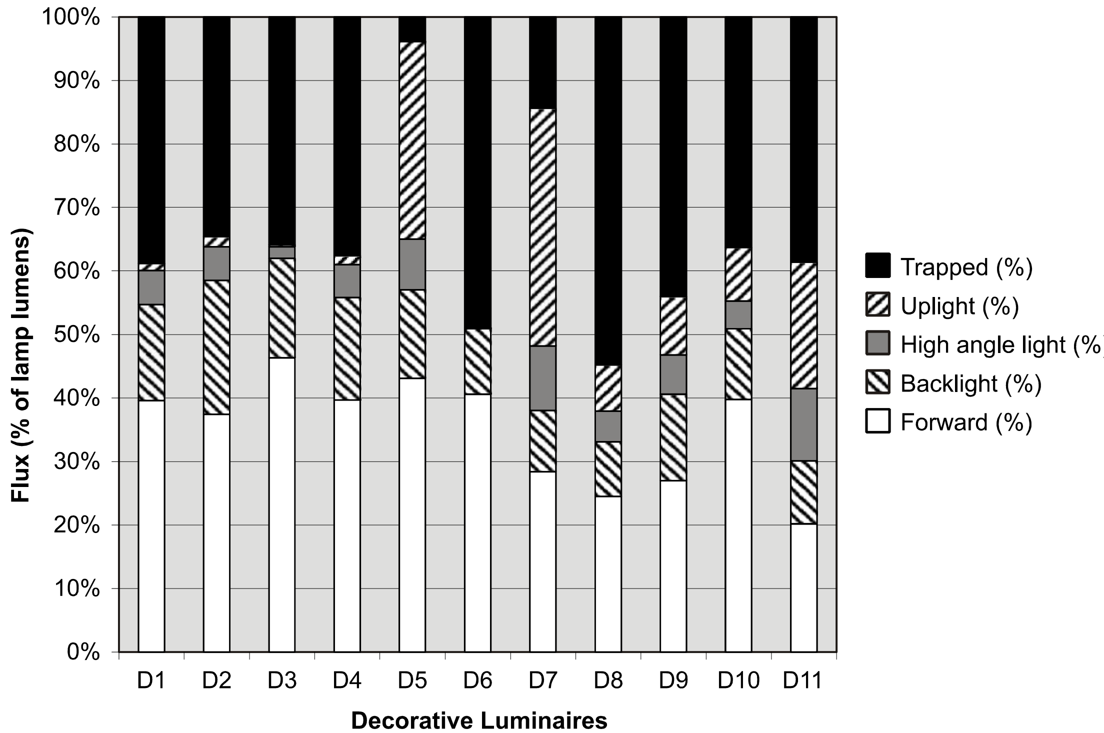


Figure 4-8. Comparison of 150 W MH and HPS decorative luminaires.

Table 4-5. Classifications for the decorative luminaires in Figure 4-7.

Luminaire	Luminaire Performance Classification		
	Backlight	High Angle Light	Luminaire Uplight
D1	B15-Z2	HA3	U1
D2	B21-Z3	HA3	U1
D3	B16-Z2	HA2	U1
D4	B16-Z2	HA3	U1
D5	B14-Z3	HA3	U4
D6	B10-Z1	HA1	U0
D7	B10-Z3	HA3	U4
D8	B9-Z2	HA2	U2
D9	B14-Z2	HA3	U3
D10	B11-Z1	HA2	U2
D11	B10-Z3	HA4	U4

4.4.2 Communicating the Luminous Flux Distribution of a Single Luminaire

Because LESS is based on the percentage of lamp luminous flux, the luminous flux within the angular regions for forward light, backlight, high angle light, and luminaire uplight can be easily displayed together for visual comparison. Figure 4-9 shows how this can be accomplished using a pie chart. The pie chart in Figure 4-9 represents the performance of a decorative teardrop luminaire. As Figure 4-9 illustrates, this luminaire has a high percentage of luminaire uplight.

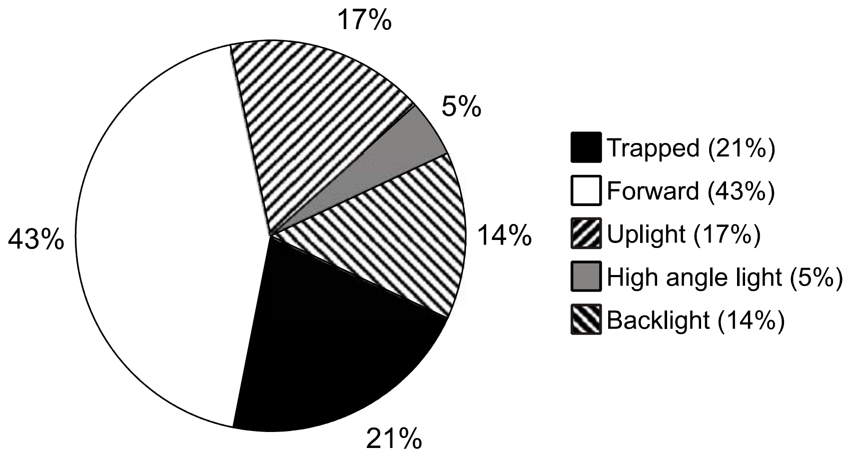


Figure 4-9. Luminous flux distribution for a decorative teardrop luminaire.

For the luminaire in Figure 4-9, the backlight is further defined with the addition of a bar chart to show the percentage of backlight in each zone (Figure 4-10). For this luminaire's 14% backlight, 3% is in Zone 1, 6% is in Zone 2, and 5% is in Zone 3. Under the backlight classification, this luminaire is a B14-Z2.

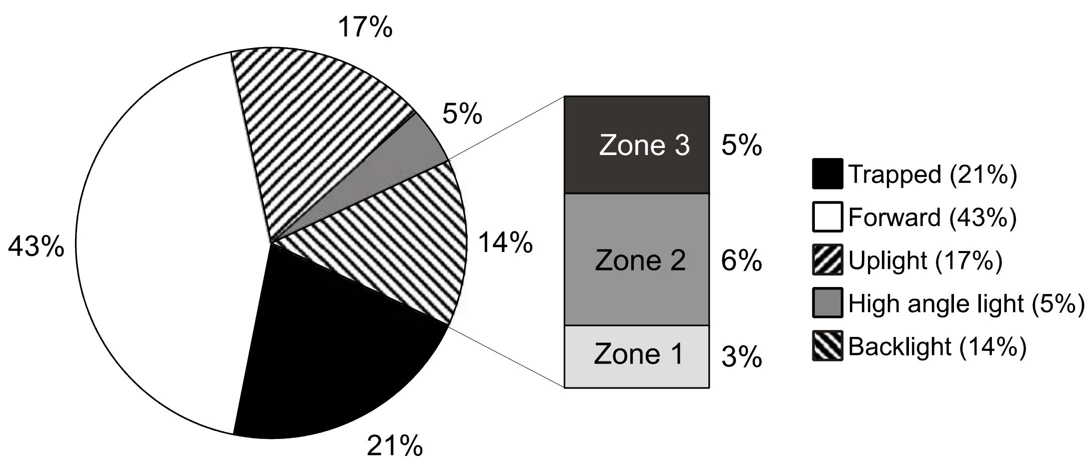


Figure 4-10. Luminous flux distribution for a decorative teardrop luminaire including the backlight in each zone.

The pie charts are very useful as a means to examine the amount of light going into each of the angular regions. It can also be helpful in examining the trapped and forward light.

4.4.3 Comparing Luminaires Having Different Wattages

LESS is also useful to compare luminaires of different wattages. Consider the luminaires in Figure 4-11. Each of these luminaires contains a lamp with a different wattage. The width of each of the bars represents relative lamp luminous flux. Therefore, the areas of each category in the histograms represents the relative amount of light.

The 250 W HPS luminaire produces significantly more forward light than the 70 W luminaire as indicated by the white areas in the histograms. The 250 W MH luminaire produces less than twice the amount of backlight as the 70 W luminaire as indicated by the similar areas in Figure 4-11. The 150 W luminaire produces more high angle light than any of the other luminaires. Additionally, the 70 W luminaire emits more forward light than the 150 W luminaire.

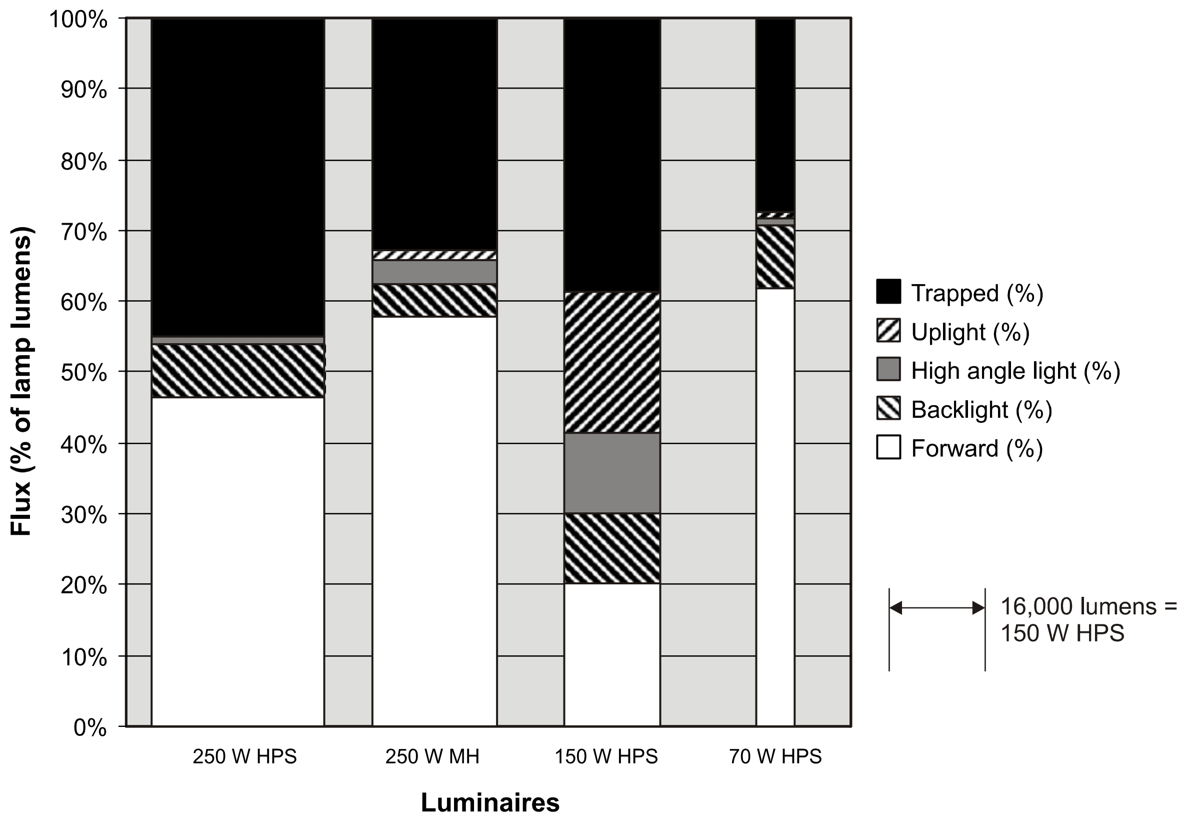


Figure 4-11. Comparison of luminaires with different lamp wattages.

5. PRACTICAL CONSIDERATIONS

For any luminaire evaluation system to have the greatest impact, issues relative to the testing of the luminaires must be addressed. While these issues are outside the scope of the proposed luminaire evaluation and selection system (LESS), they are included here for IESNA consideration.

One important issue relating to the determination of what classification a particular luminaire will have involves rounding of the measured luminous flux values as well as the precision of the measurement angles. Without consistently specified tolerance ranges for these values, test reports may not accurately represent the performance of luminaires. For example, should a luminaire with luminaire uplight of 0.1% be considered a U0 or a U1? Different laboratories may handle these issues in different ways, resulting in the potential for inconsistencies. Because such issues involve the testing of the luminaires, it is recommended that the next revision of IESNA LM-31-95, *Photometric Testing of Roadway Luminaires Using Incandescent Filament and High Intensity Discharge Lamps* (IESNA 1995) address these issues.

Additionally, the results of the *NLPIP SR: Parking Lot and Area Luminaires* show variations between the independent test results and the photometric values provided by manufacturers. This discrepancy may be due to the variability in the manufacturing processes used to fabricate the different types of luminaires. This issue must also be addressed for the proposed luminaire evaluation and selection system to have practical significance. For example, should manufacturers measure samples periodically during production in order to continue to claim that their luminaires meet the most stringent specifications, or should they report the number of luminaires upon which a specific test report is based?

6. SUMMARY

LESS provides a simple, easy-to-use communication means to impart intuitively useful information about a luminaire's performance. The system provides information about the distribution of light, both where it is and where it is not likely to be wanted. Luminaire performance can be quickly and effectively understood by specifiers. LESS uses luminous flux within a specified angular region, analogous to the average luminous intensity within that angular region, to provide intuitive information about a luminaire's performance.

Lighting products were compared using LESS. For each product, the quantity of luminous flux emitted by a luminaire into specified angular regions was calculated. The angular regions were categorized as forward light, backlight, high angle light, and luminaire uplight, the flux within each of the categories is defined in terms of the percentage of lamp luminous flux.

In general, functional luminaires have lower average values of backlight, high angle light, and luminaire uplight as compared to the decorative luminaires. However, there are wide variations with these categories. The maximum limiting values proposed for the high angle light and the luminaire uplight classifications provide an appropriate starting point for defining each of the classifications. The backlight classification indicating the zone with maximum luminous flux behind the luminaire provides an indication of the distance behind the luminaire which will be impacted by the backlight.

The criteria and classifications are most effective when they are used together with forward light as well as trapped light. Because the luminous flux for each luminaire sums to 100%, this provides a useful communication tool to understand where the light is going and the amount of light into the various angular regions. LESS graphics, along with the luminaire classifications, provide a simple means for visual comparison of multiple luminaires.

It should be reiterated that the values describing the angular regions and the criterion values proposed for specific classifications are initial proposals only. The IESNA through its committee consensus process can and should consider revising criteria and values if such revisions are determined to be more consistent with outdoor lighting practice.

7. ACKNOWLEDGEMENTS

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APPENDIX A: SUMMARY OF EXISTING OUTDOOR LUMINAIRE CLASSIFICATIONS

Existing luminaire classification systems are summarized from the *IESNA Lighting Handbook* (Rea 2000) and the appropriate recommended practice documents. The classifications are categorized according to cutoff, vertical and lateral light distributions, and the field and beam angles for sports and floodlighting luminaires. These classifications are reviewed here and in some cases, inconsistencies between definitions in these documents are noted.

A.1 Cutoff Classification

Cutoff classifications were initially developed by the IESNA as a means to describe and control glare from outdoor luminaires (Rex 1960, 1963), especially for street lighting. Later modifications were made to the classifications to control uplight. The cutoff classifications set limits on the maximum luminous intensity permitted at large angles from nadir (straight down).

The exact definitions of the IESNA cutoff classifications from the *IESNA Lighting Handbook* (Rea 2000), *IESNA RP-8-00 American National Standard Practice for Roadway Lighting* (IESNA, 2000), and *IESNA RP-20-98 Lighting for Parking Facilities* (IESNA 1998) are provided below. The cutoff classification definitions in *IESNA RP-33-99 Lighting for Exterior Environments* (IESNA 1999) are the same as the definitions in *IESNA RP-8-00*. All of these definitions use luminous intensity as a criteria at (and above) two important angles (80^o and 90^o) from the luminaire nadir to determine the cutoff classification. The limits for luminous intensity (in cd) in these classifications are defined in terms of a percentage of lamp luminous flux (in lm). The discrepancy in units is intentional; the numerical value of luminous intensity criteria is based on the lamp luminous flux.

A.1.1 Definitions from the IESNA Lighting Handbook

Full Cutoff:

> *"A luminaire light distribution where zero candela intensity occurs at an angle of 90° above nadir, and at all greater angles from nadir. Additionally, the candela per 1000 lamp lumens does not numerically exceed 100 (10%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire."*

Cutoff:

> *"A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 25 (2.5%) at an angle of 90° above nadir, and 100 (10%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire."*

Semicutoff:

> *"A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 50 (5%) at an angle of 90° above nadir, and 200 (20%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire."*

Noncutoff:

> *"A luminaire light distribution where there is no candela limitation in the zone above maximum candela."*

A.1.2 Definitions and Descriptions from IESNA RP-8-00 American National Standard Practice for Roadway Lighting and IESNA RP-33-99 Lighting for Exterior Environments

*“**Full Cutoff**: A luminaire light distribution where zero candela intensity occurs at or above an angle of 90° above nadir. Additionally the candela per 1000 lamp lumens does not numerically exceed 100 (10 percent) at or above a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.”*

*“**Cutoff**: A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 25 (2.5 percent) at or above an angle of 90° above nadir, and 100 (10 percent) at or above a vertical angle 80° above nadir. This applies to all lateral angles around the luminaire.”*

*“**Semicutoff**: A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 50 (5 percent) at or above an angle of 90° above nadir, and 200 (20 percent) at or above a vertical angle 80° above nadir. This applies to all lateral angles around the luminaire.”*

*“**Noncutoff**: A luminaire light distribution where there is no candela limitation in the zone above maximum candela.”*

A.1.3 Definitions from IESNA RP-20-98 Lighting for Parking Facilities

*“**Cutoff**: Wall mounted cutoff luminaires are typically projection-type offering good lighting for up to several times the mounting height in front of the luminaire with lateral spacings typically limited to two times the mounting height.”*

*“**Semicutoff**: Wall mounted semi-cutoff luminaires, utilizing a refracting element in conjunction with the reflector, can allow a lateral spacing of one and a half to two times their mounting height, and a longitudinal spacing of size to eight times their mounting height, provided this equipment allows the designer to meet the recommendations for both uniformity and illuminance. Also, excessive glare and the potential for significant light spill must be avoided or controlled.”*

*“**Cutoff Luminaires:** Cutoff luminaires limit high-angle light (above 80 degrees) and usually have a flat lens to provide a shielded light source with resultant low brightness and glare. They are limited to direct lighting only, and spacings must be closely related to mounting height to achieve a good design by overlapping the individual light patterns. (Full cutoff luminaires are those where zero candela intensity occurs at an angle of 90°, and at all greater angles from nadir.)”*

*“**Non-Cutoff Luminaires:** Non-cutoff luminaires are most commonly available with a dropped luminous diffusing lens or cover element to allow wider spacings. However, because of the typically low mounting heights, glare control is essential. This may dictate lower-wattage units and locating the luminaires out of the driver’s direct field-of-view. These units may be adapted for higher ceilings or wall mounting and may provide the best combination of horizontal and vertical illuminance. Consideration should be given to the environmental requirements of such equipment. Indirect surface-mounted luminaires are available. With good wall reflectances and assuming that adjacent building surfaces are properly maintained, non-cutoff luminaires can provide good visibility.”*

A.2 Differences in Cutoff Definitions

There are discrepancies in the definitions of the cutoff classification types, depending upon the source of the definition.

A.2.1 High Angle Light

For the purpose of this report, high angle light is defined as the light emitted by a luminaire at vertical angles above 80° from nadir. In the *IESNA Lighting Handbook*, the restriction on high angle-light is given in terms of the luminous intensity "*at a vertical angle of 80° above nadir,*" for all lateral angles around the luminaire. However, in IESNA RP-8-00, the high-angle light restriction is given in terms of the luminous intensity "*at **or above** a vertical angle of 80° above nadir,*" for all lateral angles. The most likely underlying assumption for the definitions in the *IESNA Lighting Handbook* is that the luminous intensity at angles higher than 80^o from nadir is lower than at 80^o. This type of inconsistency may result in classification of cutoff in instances where the intensity values for vertical angles above 80° are greater than the intensity value at 80°.

A.2.2 Uplight

Uplight is defined in this report as the light emitted by a luminaire at vertical angles above 90° from nadir. There is also an inconsistency between the *IESNA Lighting Handbook* and IESNA RP-8-00 in regard to the portion of the cutoff definitions that addresses uplight. The restriction on uplight in the *IESNA Lighting Handbook* is given in terms of luminous intensity "*at an angle of 90° above nadir*" except for the full cutoff definition where it is given in terms of the 90° angle and all angles above this angle. In IESNA RP-8-00, the restriction is always given in terms of 90^o and above.

Again, this discrepancy is probably based on an underlying assumption that the luminous intensity for all luminaires at angles higher than 90^o from nadir is lower than at 90^o. This type of inconsistency may result in inconsistent classification of cutoff in instances where the intensity values for vertical angles above 90° are greater than the intensity value at 90°.

A.3 Qualitative Descriptions of Cutoff Classifications in Application Guidelines

A.3.1 Parking Area Lighting

For the sections in IESNA RP-20-98 where cutoff is discussed, the definitions are not consistent with the *IESNA Lighting Handbook* or with IESNA RP-8-00. In both instances in IESNA RP-20-98, descriptions include light coverage and spacing related to mounting height. This is confusing because light coverage and spacing are more appropriately covered by the IESNA vertical and lateral light distribution classifications. The descriptions further use physical characteristics of the luminaires (e.g., flat or dropped lens) in the characterization of different cutoff classifications.

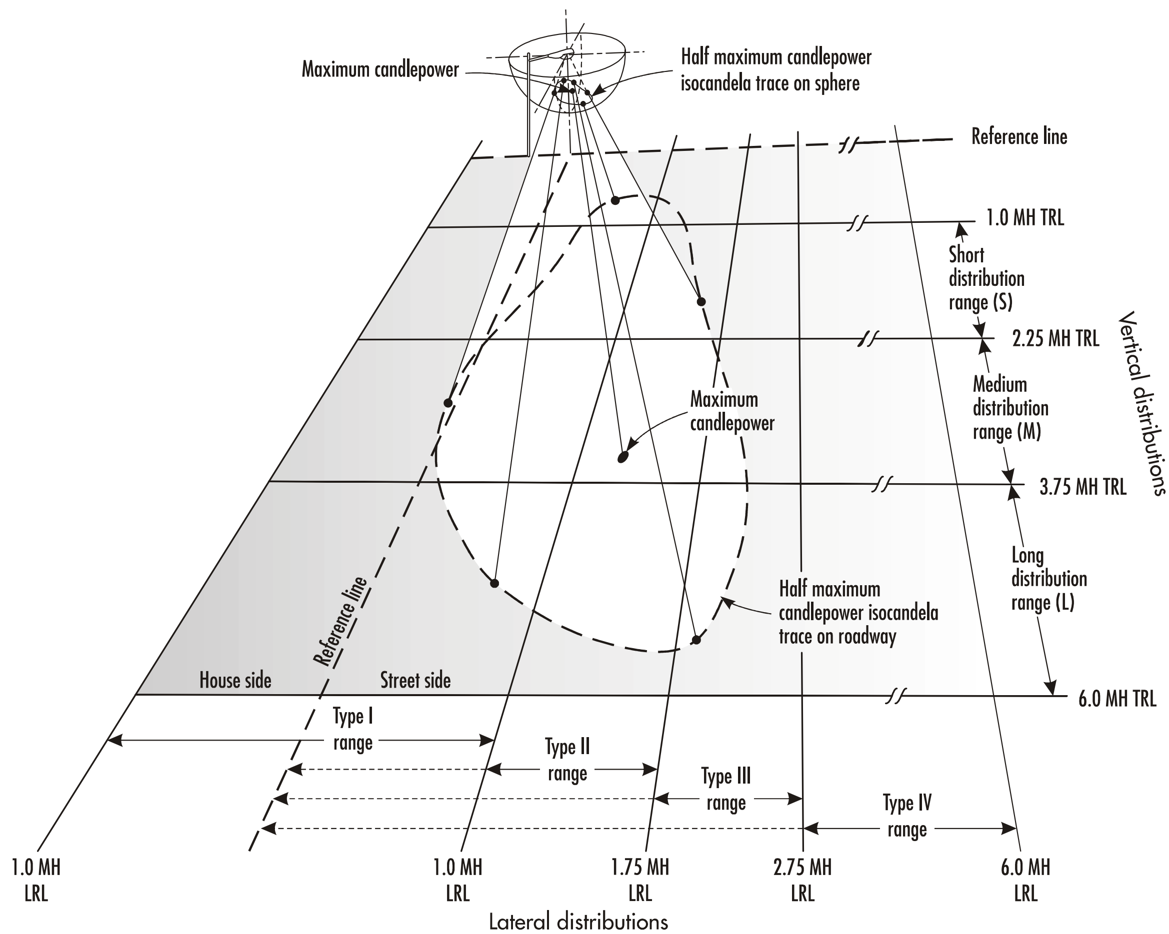
A.3.2 Sports Lighting

The recommended practice, *IESNA RP-6-01 Sports and Recreational Area Lighting* (IESNA 2001), also refers to a "*full cut off*" type of floodlight, in which the luminaire is "*shielded above the plane of the luminaire*," which presumably meets the 90^{o} and above criterion for full cutoff roadway lighting luminaires but is silent with respect to luminous intensity at other angles.

A.4 Vertical and Lateral Light Distribution Classifications

Vertical and lateral light distribution classifications are used to select luminaires for given lighting applications by providing information about the shape of the beam on the ground.

As summarized in the *National Lighting Product Information Program (NLPIP) Specifier Report (SR): Parking Lot and Area Luminaires* (McColgan et al. 2004), a luminaire light distribution is defined in terms of a vertical light distribution classification and a lateral light distribution classification (see Figure A-1). Vertical light distribution classifications are Short, Medium, or Long. Lateral light distribution classifications are Type I, II, III, IV, and V. The vertical light distribution classification is defined by where the maximum intensity (cd) lies relative to the transverse roadway lines (TRL) and categorizes how far down the road the beam extends. The lateral distribution classification is calculated based on the vertical classification (Short, Medium, Long) and the location of the half-maximum-intensity (cd) trace relative to longitudinal roadway lines (LRL). The lateral light distribution classification categorizes the width of the distribution. An example of a Medium Type III luminaire is shown in Figure A-1.



(McColgan et al. 2004)

Figure A-1. Diagram showing vertical and lateral IESNA distribution classifications; in this figure, this luminaire is classified to have a Medium Type III distribution.

Because of the complexity of determining the vertical and lateral light distribution, the IESNA in most of its documents provides simple diagrams to illustrate the ground illuminance patterns of the different lateral light distributions (see Figure A-2). Specifiers typically use, and expect, these simple patterns in selecting luminaires. Unfortunately, these simple patterns are only approximations and there can be significant variations among the shapes of the ground illuminance patterns for a given lateral distribution (e.g., some Type III distributions look more like Type IV distributions or vice versa). Therefore, problems arise because the luminaires may not perform as expected.

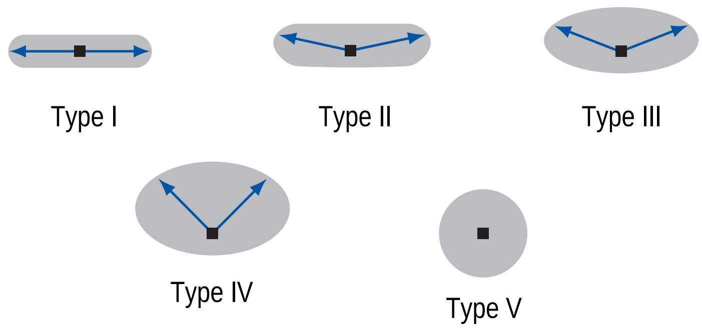


Figure A-2. Simplified drawings of lateral light distributions.

While not part of the IESNA lateral light distribution classifications, some manufacturers use terms such as *forward throw* to refer to the Type IV classification, or *asymmetric* to refer to the Type III classification. They also offer other non-standardized lateral light distribution classifications such as *square* or *rectangular*. These are identified as Type V-square and Type V-rectangular. While not part of the IESNA vertical light distribution classifications, the lighting industry sometimes uses another non-standardized classification known as *very short*, where the maximum intensity lies before the 1 MH TRL.

The vertical and lateral distribution classifications of luminaires are not given directly in *IESNA RP-20-98 Lighting for Parking Facilities*. However, the document does refer to the luminaire classifications in *IESNA RP-8-83 American National Standard Practice for Roadway Lighting* (IESNA 1983). The vertical and lateral classifications for luminaires in IESNA RP-8-83 are the same as in IESNA RP-8-00. IESNA RP-8-00 is the current recommended practice document for roadway lighting.

In *IESNA RP-33-99 Lighting for Exterior Environments* the lateral distribution classifications are described simply in terms of setback (see Table A-1) from the roadway using the simple shapes in Figure A-2, with an additional reference to IESNA RP-8-83 for the precise definitions.

Table A-1. Descriptions of lateral distribution classifications from IESNA RP-33-99.

Classification	Description
Type I	Closest setback from roadway (or mounted over roadway)
Type II	Greater setback than Type I, less than Type III
Type III	Greater setback than Type II, less than Type IV
Type IV	Greatest setback from roadway
Type V	Axially symmetric; produces a circular illuminance pattern

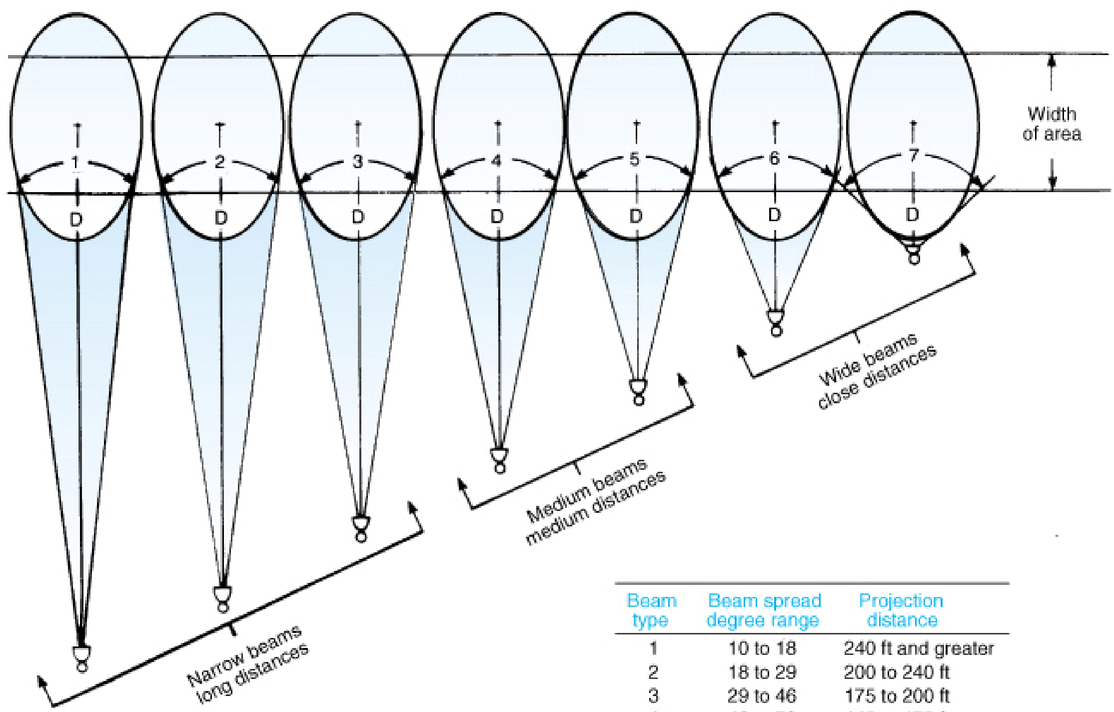
A.5 Beam and Field Angles for Sports Lighting

For luminaires used in outdoor applications such as sports lighting, as well as other applications such as outdoor sales areas, the luminaire distribution can be thought of a symmetric or asymmetric cone, and is classified according to the cone angles. The beam angle is defined in the *IESNA Lighting Handbook* as the angle within which a luminaire's luminous intensity is at least 50% of its maximum. This classification assumes a monotonic luminous intensity distribution with a single peak in the center of the beam distribution. The field angle is defined in the *IESNA Lighting Handbook* as the angle within which the luminous intensity is at least 10% of maximum.

For luminaires producing a symmetric (circular) cone, a single beam and field angle are used. For luminaires producing an asymmetric (elliptical) cone, two beam angles and two field angles are used, one referring to the width of the distribution in the horizontal direction and one in the vertical direction.

The National Electrical Manufacturers Association (NEMA) has developed a system of classification based on the field angle (deg), as illustrated in Figure A-3. For luminaires producing asymmetric cones, the Type is specified in two axes, as Type horizontal × vertical. For example, a luminaire with a horizontal field angle of 50^{o} and a vertical field angle of 25^{o} is commonly classified as a Type 4 × 2 luminaire.

IESNA RP-20-98 refers to the *IESNA Lighting Handbook* for the available floodlighting distributions. *IESNA RP-6-01 Sports and Recreational Area Lighting* includes the NEMA beam type classification system.



Beam type	Beam spread degree range	Projection distance
1	10 to 18	240 ft and greater
2	18 to 29	200 to 240 ft
3	29 to 46	175 to 200 ft
4	46 to 70	145 to 175 ft
5	70 to 100	105 to 145 ft
6	100 to 130	80 to 105 ft
7	130 and up	under 80 ft

(Rea 2000)

Figure A-3. Illustration of NEMA classification system for field angles.

APPENDIX B: CRITICAL EVALUATION OF EXISTING LUMINAIRE CUTOFF/DISTRIBUTION CRITERIA

B.1 Purpose of Current Cutoff Classification System

The current IESNA cutoff classifications were developed primarily as a means to control glare from roadway lighting installations (Rex 1960, 1963). The primary concept behind them is that high values of luminous intensity at high angles (e.g., 80^o) from the luminaire nadir will result in high illuminances at the eyes of drivers; these in turn will result in high veiling luminances or subjective impressions of discomfort. Part of the rationale for the 80^o angle used in these classifications was due to the typical cutoff angle of windshields on vehicles during the time the classifications were developed (Rex 1955, 1963, 1967). Direct views of roadway luminaires would be blocked by the roof of most vehicles of the time, obviating restrictions at these smaller angles.

As concerns about light trespass and sky glow have increased in recent decades, specifiers and end-users have attempted to use the IESNA cutoff classifications to address not only glare but also light trespass, excess illumination of an area not meant to be lighted, and sky glow, brightening of the nighttime sky caused by direct and reflected light from outdoor lighting that is scattered by the atmosphere.

In this section, the cutoff classifications (as well as other distribution classifications) are evaluated in terms of their potential to meaningfully characterize light trespass, glare, and sky glow.

B.2 Light Trespass

Light trespass is often quantified in terms of a maximum permissible illuminance along a property boundary or other relevant location. Indeed, it is very difficult to predict light trespass potential from the cutoff classification system. McColgan et al. (2004) calculated the vertical illuminance (at a height of 1.5 m) from a series of semicutoff, cutoff and full cutoff luminaires at distances corresponding to one and two luminaire mounting heights (approximately 10 and 20 m) from the luminaire. These illuminances ranged from 4 to 14 lx at one mounting height and from less than 1 to 10 lx at two mounting heights, with no significant differences among the cutoff classifications.

There is an incorrect assumption that the existing cutoff classifications provide an indication of a luminaire's potential to cause light trespass. The assumption is that because the high angle light and uplight are controlled, light that may cause light trespass is also minimized. This is not necessarily true. Light trespass is site-specific. The site geometry, location and orientation of the luminaire, and the performance characteristics of the luminaires are all factors in determining whether light trespass will be minimized.

B.3 Glare

Many existing formulae for predicting the veiling luminance associated with a particular degree of disability glare require two important characteristics of the glare source: the illuminance at the observer's eye and the location of the glare source in the line of sight

(Rea 2000). Both of these values are highly dependent upon the geometry and layout of a specific lighting installation. However, for roadway lighting at least, assuming the cutoff characteristics of vehicle windshields and common ranges of luminaire mounting heights, the luminous intensity at 80^o from nadir and above is, on the surface, a reasonable measure for comparing the glare potential of outdoor luminaires.

Recognizing that the geometry of modern vehicles can be very different from the assumptions made by Rex (1955, 1963, 1967) in earlier research, McColgan and Van Derlofske (2004) calculated the veiling luminance from a series of semicutoff, cutoff and full cutoff roadway luminaires at varying distances from the luminaire. Consistent with what might be expected based on their cutoff classifications, the full cutoff luminaires had the lowest veiling luminances at a distance corresponding to an angle of 80^o from nadir, and semicutoff the highest of the three types (these are based on averages; there were wide variations among individual luminaires). However, at lower angles, even at just 70^o from nadir, these relationships were reversed, indicating that full cutoff luminaires might produce *higher* veiling luminances than semicutoff luminaires.

The requirements for cutoff and full cutoff luminaires in the 80^o to 90^o zone from nadir are the same, implying that there should not be any differences between these two classifications in the amount of light emitted in this zone. However, an analysis by McColgan and Van Derlofske (2004) indicated that there were differences between these two types of luminaires, with cutoff luminaires producing more light in the high angle light region. This may be caused by the additional requirement that full cutoff luminaires also have no luminous intensity at 90^o from nadir and above. Meeting this requirement might require optical designs that affect the distribution of the luminaire below 90^o, demonstrating some of the difficulties of combining requirements for two separate angular regions into a single classification system. The combination of requirements for two angular regions into a single system can also be a point of confusion. It is commonly thought that any luminaire with a flat glass lens and producing no light above 90^o from nadir, for example, must be a full cutoff luminaire, when in fact, such a luminaire could be classified as semicutoff or even noncutoff if the luminous intensity between 80^o and 90^o from nadir is sufficiently high.

Thus, the existing cutoff classification appears to have some utility at predicting disability glare at relatively large distances from a luminaire, but at distances corresponding to viewing angles less than 80^o from nadir, the classification system essentially falls apart. Additionally, the fact that the same cutoff classification is used to characterize both high angle light and uplight leads to ambiguity. It is not immediately apparent, or sometimes not apparent at all, if a semicutoff luminaire has excess glare light, uplight, or both.

With respect to discomfort glare, the sensation of annoyance or pain that is often associated with bright sources in the field of view, formulae for predicting this response (e.g., Schmidt-Clausen and Bindels 1974) also require the illuminance at the observer's eye and the location of the glare source in the field of view, and further require the overall adaptation luminance. Thus, many of the same limitations exist when using the classifications to predict discomfort glare as do when predicting disability glare, with the additional point that some indication of the expected light level is also needed. Since this last parameter is absolutely dependent upon the specifics of a particular lighting installation because different lighting installations require different light levels, it is very difficult to predict discomfort glare from the cutoff classification.

B.4 Sky Glow

Scattered light in the atmosphere is a function of the light emitted in the upward direction from the luminaire in combination with light directed downward that is reflected from the pavement and ground surfaces. The amount of light is properly characterized in terms of luminous flux (lm) but the present IESNA cutoff classifications are given in terms of luminous intensity. In theory, as described by Bullough (2002), a narrow pencil beam directed upward from a luminaire having a luminous intensity (in cd) that is just over 2.5% of the numerical value of the lamp luminous flux (in lm) will disqualify a luminaire from being in the cutoff category, even though such a luminaire would emit only a small fraction of its luminous flux upward, while a second luminaire with a uniform luminous intensity in the upward zone (in cd) of just under 2.5% of the numerical value of the lamp luminous flux (in lm) would emit 16% of the lamp luminous flux upward, while retaining its classification as cutoff type.

Table B-1 lists the ranges of luminous flux that are permitted above 90^o from the luminaire's nadir for each cutoff category; it can be seen that in each case the range includes zero lumens (McColgan 2003). The wide potential for overlap renders the cutoff classification useless in predicting sky glow.

Table B-1. Ranges of luminous flux above 90^o from nadir that are permitted by each of the current cutoff classification types.

Luminaire classification	Range of allowable lumens emitted upward	Range of allowable lumens emitted between 80° and 90°
Full cutoff	0	0 - 11%
Cutoff	0 - 16%	0 - 11%
Semicutoff	0 - 31%	0 - 22%

A number of researchers have investigated the ability to predict sky glow for outdoor lighting applications. Of course, the cutoff classification system is silent with respect to light below an angle of 80^o from nadir, which presumably is largely forward light. However, this light also contributes indirectly to sky glow via reflection. Nonetheless, if a classification system could correctly organize luminaire types into their rank order in terms of potential for sky glow, such classifications would be useful.

Sundaram et al. (2002) measured and calculated the upward illuminance on a plane above a parking lot lighting installation using a range of luminaires (full cutoff, cutoff and semicutoff types) and found that the upward illuminance (including both direct upward light and reflected light from the pavement and ground) was largely similar among the luminaire types, but with still greater variation for cutoff than for full cutoff, and greater variation for semicutoff than for cutoff types. In other words, most of the luminaires performed similarly regardless of classification category, but the less restrictive categories had greater potential for "outliers" resulting in increased overall upward luminous flux. However, the classification system does not distinguish among those luminaires with little upward flux and those with a large amount of upward flux.

Keith (2003) performed a series of roadway lighting calculations using full cutoff, cutoff, semicutoff and noncutoff luminaires, in which the illuminance, luminance, veiling luminance criteria from IESNA RP-8-00 were met for a range of roadway types. The method was similar to that used in an earlier paper in which roadway and surrounding surfaces were modeled as diffuse reflecting surfaces (Keith 2002). Keith calculated unit uplight density values for a series of installations in which luminaire spacings were optimized to meet the IESNA criteria. Correlations between these uplight values and the classification types were almost always lower than the correlations between uplight and the percentage of directly-upward luminous flux, as well as the correlations between uplight and the classification scheme proposed by Bullough (2002) to address the deficiency of the present IESNA system at predicting uplight from luminaires. This underlies the importance of using luminous flux rather than luminous intensity to characterize the potential for sky glow.

In a similar vein to the work by Sundaram et al. (2002) and by Keith (2002, 2003), Laporte and Gillet (2003) evaluated the total uplight from roadway lighting systems (using the directional reflection characteristics of common roadway pavement materials), and found little correlation between this value and the cutoff type of luminaires used. It was almost always possible to select what might be predicted to be a poor performance type (e.g., semicutoff) and optimize the layout to result in comparably lower total uplight than a layout using cutoff or full cutoff types.

The application research of Sundaram et al. (2002), Keith (2002, 2003) and Laporte and Gillet (2003) convincingly point out the shortcomings of cutoff classification at predicting upward light that contributes to sky glow. Indeed, any approach based on luminous intensity rather than luminous flux seems unlikely to be able to serve as a useful component of any sky glow prediction (Bullough 2002, McColgan 2003).

B.5 Lateral/Vertical Distributions and Beam/Field Angles

While not cutoff classifications per se, the lateral and vertical distributions of roadway luminaires are often used in preliminary selection of luminaires for specific applications. In a sense, lateral and vertical distribution types are a similar concept to that of beam and field angles used for sports and other floodlighting applications (Rea 2000). All of these approaches use a luminous intensity criterion (such as 50% or 10% of maximum) and provide the angle within which the luminous intensity of the luminaire is at or above this criterion value. They provide a rough estimate of the size of the "beam" produced by the luminaire.

They do not provide much additional guidance beyond the current IESNA cutoff classification system to the specifier regarding the likelihood of a luminaire to contribute to light trespass, glare, or sky glow, as they are based in luminous intensity rather than luminous flux, and generally not applicable to the angles of interest for light trespass, glare, or sky glow.

The increased use of computer software simulations as a tool by lighting specifiers as they develop layouts for installations is perhaps decreasing the practical utility of the lateral/vertical distributions and beam/field angles, since they are typically to be used to provide a “ballpark” estimate of luminaire number and spacing, with further optimization to occur with more extensive calculations. The introduction of reliable, fast computation methods allows the specifier to jump directly to an optimized spacing of luminaires based on any number of additional criteria that are of interest (e.g., veiling luminance in roadway lighting calculations).