Aspects of Recent American Research in Lighting Technology

by

Ian Lewin, Ph.D., FIES, L.C.

Lighting Sciences Inc.
7830 East Evans Road
Scottsdale, Arizona 85260
Telephone: 480-991-9260
Fax: 480-991-0375

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Author Qualifications

Ian Lewin is President of the Illuminating Society of North America, IESNA. He is also President of Lighting Sciences Inc. He holds a Ph.D. in Illuminating Engineering from the University of Newcastle upon Tyne, England, and has 32 years experience in lighting research and development, light measurement and teaching.

Dr. Lewin is a Fellow of the IESNA, and holds the society's Distinguished Service Award. He is past chairman of the Roadway Lighting Committee, and was the recipient of the 1997 IESNA Medal, the society's highest honor. Ian is also an honorary member of the Institution of Lighting Engineers, a member of the Optical Society of America and the International Society for Optical Engineering, (SPIE). He serves as alternate director for the USA for CIE division 2. He has published 120 papers and holds 22 patents.

Summary

There has been considerable activity over the last few years in North America in the field of lighting research. This paper gives a brief synopsis of several projects. Firstly, the development of a method for roadway lighting design based on observer visibility is discussed. This has now been adopted by the Illuminating Engineering Society of North America as a national standard. Secondly, efforts to characterize light trespass are presented, along with proposed limitations for a variety of environmental conditions. Thirdly, research has been continuing on the effects of lamp spectral distribution and its influence on roadway lighting, visibility and safety. It has been determined that blue-green rich sources have considerably higher effectiveness that commonly used yellow-rich sources.

Introduction

To provide a worthwhile synopsis of all lighting research activity in North America is too ambitious for a short presentation, and therefore this paper will summarize some current efforts in outdoor lighting, where much of the work has been concentrated.

The Illuminating Engineering Society of North America (IESNA) has recently approved a new recommended practice for roadway lighting, which incorporates the specification and calculation of visibility. This is the result of over 15 years of effort. Work also is underway in the area of light trespass, with a 10 year project just having been completed. Possibly the most exciting and potentially beneficial work, however, is in the subject of visibility at mesopic lighting levels.

Roadway Lighting Recommendations

Under the designation RP8, IESNA produces a recommended practice for the lighting of roadways for Canada, Mexico and the United States. This practice becomes a US standard after adoption by the American National Standards Institute, ANSI. In 1983, roadway luminance was added as a design criterion to serve as an alternative to illuminance.(1) Since that time, the IESNA Roadway Lighting Committee has been investigating driver visibility with the ultimate goal of producing a revised practice incorporating visibility. Earlier this year, this aim was realized with the approval of the new RP8.(2)

In the new practice, visibility does not replace the illuminance and luminance methods of design. Rather, it is provided as an alternative method. The committee hopes that this will provide designers with the ability to become familiar with the concepts and procedures involved, without creating an undue burden of the new techniques being legally mandated.

Background of the Visibility Method

It is well known that the detection of an object on a roadway is greatly affected by the contrast of that object to the road surface. Common practice is to perform lighting design based on achieving a certain level and uniformity of roadway luminance. This ignores the fact that contrast is based on a luminance *difference*; a roadway lighting system may provide a high and uniform road surface luminance, yet an object on that surface may have a visibility below the eye's threshold if contrast is inadequate. There is a need for design practice to incorporate the specification and provision of luminance contrast as a means of improving the visibility of hazards. This, however, is not an easy task.

The nighttime driving scene is tremendously variable. To produce a useable system of lighting design based on visibility, some standard conditions must be adopted. The IESNA practice uses an array of small flat vertical targets, placed over a grid on the roadway. The locations are identical to those used for roadway luminance calculations. The targets are 18 cm. square, and are diffuse with 50% reflectance.

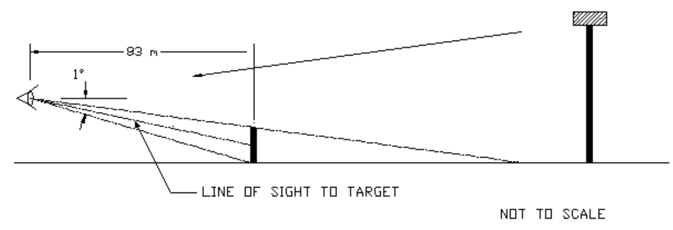

Figure 1. Driver and target standard geometry. (Not to scale)

As shown in figure 1, the observation geometry also is identical to that used for roadway luminance calculations (although North American practice and CIE are slightly different). There are three luminance components which influence the visibility of the target: the target luminance itself, the luminance of the background, and veiling luminance or glare. As shown by figure 2, the target will be seen in contrast to the roadway background around the target perimeter. This is simplified by calculating the background luminance at two points only, top and bottom center of the target.

Given these three luminances, all of which can be calculated, the visibility of each target in the array can be determined in terms of "Visibility Level," VL. VL is the ratio of target contrast to the contrast of a similar target at threshold, a measure of visibility which has been widely used.

Further assumptions are the observation time (0.2 seconds) and a driver age of 60 years. (This is the first time an IESNA committee has acknowledged that drivers do not consist entirely of 20 to 30 year old observers).

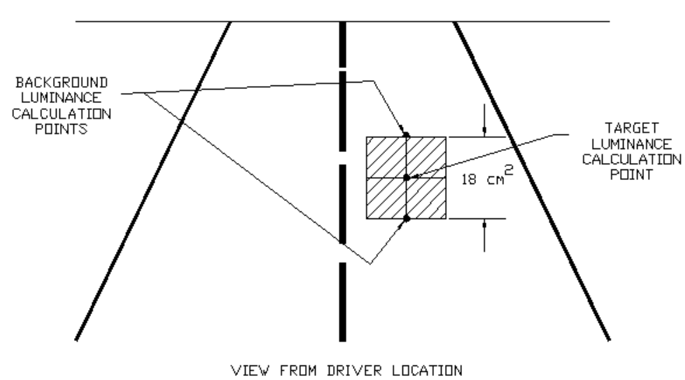

Figure 2. Driver's perspective viewpoint. (Not to scale)

An obvious problem with this, or any, assumed set of conditions is that rarely, if ever, will these conditions actually occur. The concept is, however, that by using a fixed set of conditions such as this, a common basis can be provided to be used to compare different lighting designs. Research by the IESNA visibility group has indicated that these conditions provide a good method for rank ordering of different lighting designs based on the visibility they produce.

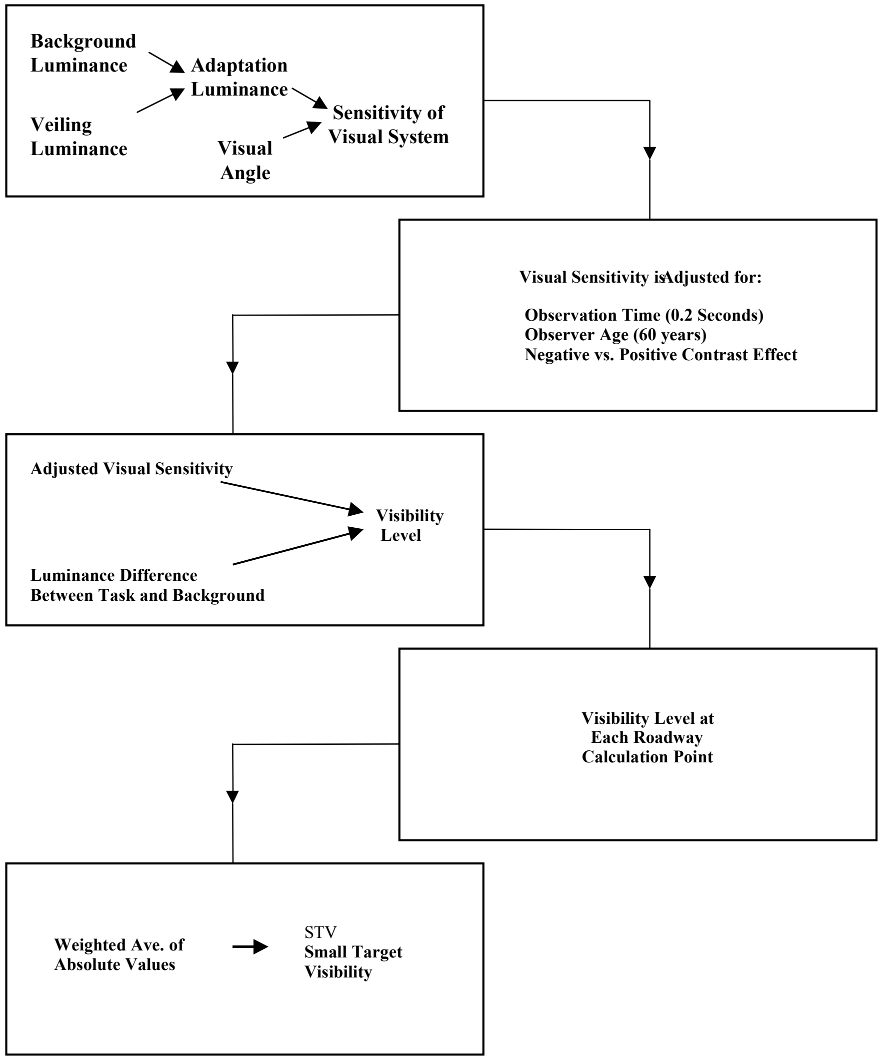

Figure 3. Computational System to Determine Small Target Visibility, STV

Visibility Calculations

The applicable calculations are complex, as visibility itself is a complex issue. Full details of the step-by-methodology are available.(2) With today's computers, however, visibility calculations can be handled with the same ease as determining illuminance or luminance.

Briefly, the adaptation luminance of the observer is found by summing the roadway surface luminance and veiling luminance. Fig.3. The observer's visual sensitivity then can be determined from the adaptation luminance and the subtended angle of the individual target. Sensitivity then is adjusted for the standard age and observation time. A further adjustment is made depending upon whether contrast is negative (target darker than its background) or positive (target lighter than its background). This adjusted visual sensitivity and the luminance difference between the target and its background yield the Visibility Level.

This calculation is repeated for each target in the array grid. A weighting function has been developed to combine the individual absolute VL values for the entire grid. The value so computed is termed "Small Target Visibility," STV.

The new recommended practice specifies the minimum STV levels to be achieved for a full range of roadway classifications, table 1. It will be noted that roadway luminance levels and uniformities are incorporated in the STV table. This is to mitigate the effect of oncoming vehicle headlights, which are not otherwise taken into account in the STV procedure.

ROAD AND AREA CASSIFICATION		**STV CRITERIA**	**LUMINANCE CRITERIA**		
ROAD	PEDESTRIAN AREA CLASSIFICATION	Wtg. Avg. VL	L_{avg}* Cd/m^2 Median <7.3m.	L_{avg}* Cd/m^2 Median ≥ 7.3m.	Max. Uniformity Ratio L_{max}/L_{min}
Freeway "A"		3.2	0.5	0.4	6.0
Freeway "B"		2.6	0.4	0.3	6.0
Expressway		3.8	0.5	0.4	6.0
	High	4.9	1.0	0.8	6.0
Major	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
	High	3.8	0.6	0.5	6.0
Collector	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
	High	2.7	0.5	0.4	10.0
Local	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

Table based on a 60 year old driver with normal vision, an 18x18cm 50 percent reflective target, and a 0.2 second fixation time. Data courtesy of IESNA.

Future Visibility Work

The IESNA committee, having completed the 1999 version of RP8, now is commencing the task of developing the next practice. The newly issued document is recognized as being only a first step; our knowledge of the complex issues involved in roadway lighting and visibility is far from complete. For example, it has not yet been possible to establish a significant correlation between STV and accident rates in the field although there are experimental data which strongly suggest why such a correlation should exist. This is probably due to the many confounding factors which influence road accidents, other than visibility. The lack of success in finding clear correlation also may be due partly to the fact that many accidents are believed to result from objects which appear firstly in the peripheral field; this is not evaluated in the STV procedure.

Clearly there is much further work to be done in view of the complexity of the issues.

We look forward to working with other groups in the investigation of alternative systems or improvements to that which has been developed.

Light Trespass

There is a growing concern in North America over obtrusive light. Light pollution and sky glow have long been a problem for astronomers. However, now the public is becoming aware of light trespass, the spillage of light into unwanted areas and the brightness of nighttime sources. There is a powerful movement toward local laws which regulate light trespass. Unfortunately, however, there is no national coordination between the regulations of individual municipalities, counties and states. Furthermore, many regulations are drafted by persons inexperienced in lighting design, with the result that rules range from comical to hopelessly complex.

A project has recently been completed to analyze light trespass in a way that may be helpful to all those who are concerned with the subject.(3) The goals of the project were as follows:

Define light trespass. Is it the presence of bright sources in view at night? Is it the lighting of areas which preferably should be dark?

Can light trespass be defined numerically? Can levels be specified in some way?

Can numerical limitations of light trespass be developed?

Seminars on the subject were held where the ideas of participants were solicited. Questionnaires were issued. Information was gathered on the types of nighttime lighting which people find objectionable. Much useful information was collected to form a framework for research investigations.

Experiments were developed wherein a variable test source of light trespass was used under a variety of nighttime conditions. The source could be varied in its luminance, size, orientation and location. A rating scale was developed that expressed the degree to which observers found the source objectionable. Numerous tests were conducted using multiple observers and test conditions. Figure 4 presents sample results for one set of experiments.

The conclusions from the work were not unexpected:

- The degree to which light trespass is objectionable increases with increasing source luminance
- Increased source area, for a given luminance, increases the level of objection.
- The environment (rural, suburban, urban) and ambient light level affects the reaction to light trespass
- The degree of objection decreases as distance to the source increases.

While unsurprising, the results are useful because they establish a framework upon which to base recommendations for the control of light trespass. Space does not permit a presentation of the full results and rationale for how they may be used. Readers who are interested in the complete investigations and extensive background information may obtain these through reference 3. In summary, the conclusions were:

- A system of environmental classification is necessary, and light trespass limitations should be appropriate for the environment.
- The same variables influence the level of objection to sources of light trespass as control the illuminance level at the eye, on a plane perpendicular to the line of sight. Such illuminance values can be used as a simplified method of specifying limitations to light trespass.
- Lighting curfews may be a useful way of reducing the effect of light trespass. Two sets of light trespass limitations can be specified, for pre- and post-curfew.

Table 2 provides suggested maximum levels of eye illuminance, (lux perpendicular to the line of sight), for a single luminaire or group of luminaires on a pole. Because of the highly subjective nature of light trespass, however, these should be carefully evaluated to determine their acceptability and applicability under a given set of circumstances. The values in table 2 are derived from a variety of sources, which include the present US research and work performed in Australia and Europe. The aim of the proposed values is to prevent the Objectionable Rating, figure 4, from reaching 4 during pre-curfew conditions, and staying at 2 or less for post-curfew hours. Further details and rationale are provided in reference 3.

Table 2
Suggested Light Trespass Limitations

Environmental Zone*	Maximum Illuminance at Eye (Lux)	
	Pre-Curfew	Post Curfew
E1	1	0
E2	3	1
E3	8	3
E4	15	6

Per proposed CIE definitions:

E1. Intrinsically dark areas
E2. Low ambient brightness areas
E3. Medium ambient brightness areas
E4. High ambient brightness areas

The IESNA is now in the process of drafting a technical memorandum on this subject. It is hoped to produce a unified approach to rules pertaining to light trespass for the benefit of lighting designers and users alike.

Lamp Spectral Effects

This is a subject of major interest and importance. Several research projects have been conducted which lead to the same conclusion: by selection of the proper spectral distribution of the light source, visibility may be enhanced while energy levels can be reduced.(4,5,6,7,8) Ironically, this far-reaching conclusion has, as its basis, information which has been known since the mid-nineteenth century!

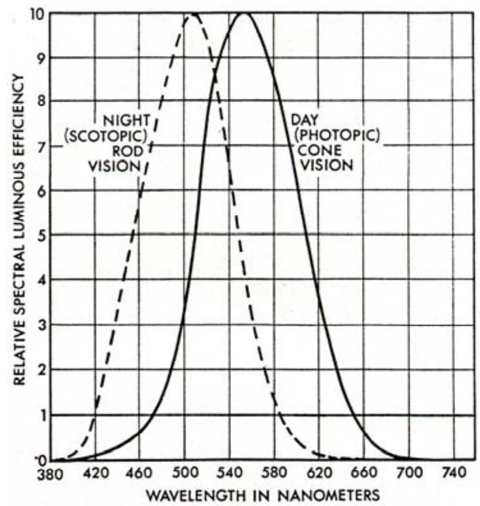

Figure 5: The V(λ) curve (bold) for photopic vision, and the V'(λ) curve (dashed) for scotopic vision.

The problem, or rather the opportunity, lies in *the inadequate international definition of the lumen*. The CIE eye sensitivity curve, V(λ), is based on 2° foveal vision, which constitutes only a small part of our visual field. Moreover, at night, the visual response curve of the eye shifts such that the V(λ) curve is no longer applicable. Figure 5, bold curve, shows the V(λ) curve which is based on the "photopic" response curve of the cones of the eye. These are fully active only under moderate and high light levels. The dashed curve, figure 5, shows the "scotopic" curve applicable to the rods of the eye, which are active at very low light levels.

Under most nighttime lighting levels, under 3 cd/sq.m., conditions are "mesopic" and the response curve of the eye, outside the central 2°, is between the two curves shown in figure 5.

The lumen output of a lamp is defined as the summation of the power at each wavelength multiplied by the eye sensitivity at the respective wavelengths.

$$\text{Lamp Lumens} = K \sum \text{Power}(\lambda) \,.\, V(\lambda)\ \Delta\lambda$$

λ denotes wavelength

Clearly, if V(λ) is inapplicable under certain given lighting conditions, then the lumen output of the lamp calculated using V(λ) is not valid for those conditions. The *effective* lumen output may be much greater or much less when the truly applicable visual sensitivity function is used.

A good example of this is provided by figures 6 and 7. Each figure shows a spectral output curve of a lamp using superimposed over the eye sensitivity curves, to the same

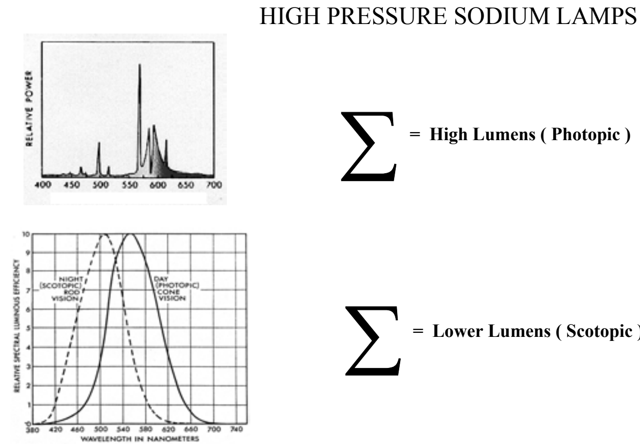

Figure 6: Spectral Power Distribution of a typical high pressure sodium (HPS) lamp.

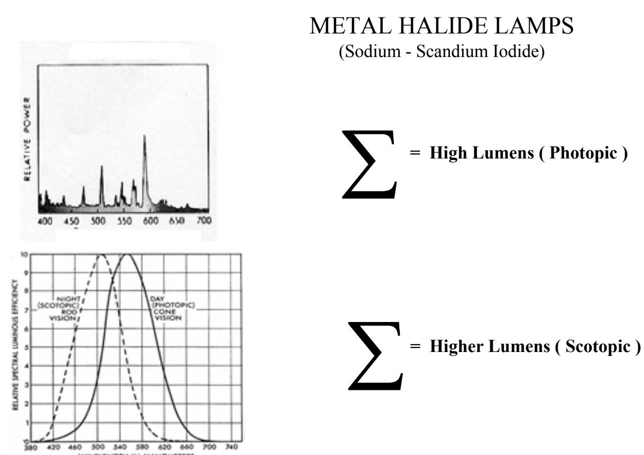

Figure7: Spectral Power Distribution of a typical metal halide lamp.

horizontal wavelength scale. Figure 6 shows a yellowish source, (high pressure sodium), while figure 7 is a "white" source, (sodium-scandium metal halide).

The yellow source, figure 6, has a strong spectral peak which is aligned close to the peak sensitivity of the photopic eye. This source has high lumens. As the light level reduces, however, the peak eye sensitivity moves to shorter (blue-green) wavelengths, and the effective output of this source sharply reduces. This is because the yellow output is no longer near the eye's maximum sensitivity.

For the white source, figure 7, just the opposite is true. Firstly, the rated lumen output of the lamp is lower, as it has a more balanced spectrum and lacks predominant output in the yellow region. Secondly, as the light is reduced to roadway levels, the eye moves its peak sensitivity towards the blue-green wavelengths. Thus the effective lumen output of this source actually increases.

Numerically, this effect at low street lighting levels can create effective lumens from the white source which may be double that of the yellow source.(4)

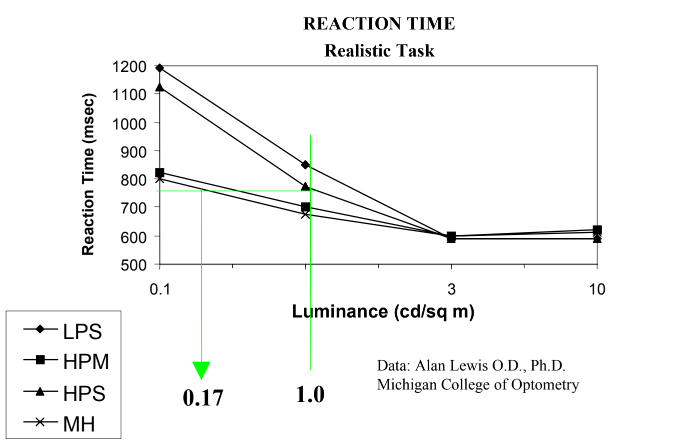

Figure 8. Determination of the effective metal halide level.

In practice, however, the effects of white versus yellow light are of an even greater magnitude than would be expected from the above. The work of Dr. Alan Lewis, and Professor Mark Rea and his colleagues have shown that when practical visual tasks are involved, the differences between light sources increases further.(5,6)

Figure 8 illustrates data from the work of Dr. Lewis involving reaction times in a simulated driving experiment, performed using different light sources. It can be seen that when vision is photopic (3 cd/sq.m. and above), the reaction time is identical for all light sources. As the light level reduces through the mesopic range, however, the curves diverge: at a level of 0.1 cd/sq.m the low and high pressure sodium reaction times are roughly 50% longer than for mercury and metal halide.

Figure 8 shows how the equivalence between two sources can be determined. Given a plot as shown in the figure, and using the construction lines shown, it can be seen that at 1.0 cd/sq.m., high pressure sodium produces a reaction time for these particular experimental conditions of 800 milliseconds. The level for metal halide to produce an identical reaction time is 0.17 cd/sq.m. Thus for this task, metal halide lighting has 6 times the effectiveness of high pressure sodium (1.0 ÷ 0.17).

Work is continuing in this area to evaluate more experimental conditions, particularly those related directly to the driving task. An IESNA group is evaluating the research to provide recommendations to the society on how to incorporate these spectral effects into design practice. It is anticipated that a TM (Technical Memorandum) will be completed on this subject within one year.

A proposal has been developed for the use of "Lumen Effectiveness Multipliers," LEM, which can be applied to the photopic, or published, lamp lumens to account for the effect of the spectral shift.(9) There appears to be the potential for significant benefits in terms of increased visibility and reduced energy usage. The work is now moving out of the research laboratories and into the political and economic areas, with involvement by the US Department of Energy, which was a major sponsor of some of this work.

Conclusion

This brief synopsis has identified a few areas of possible interest in North American lighting research. Much more is available and is usually published in the Journal of IESNA. We look forward to continued cooperation with our friends and colleagues in the United Kingdom in these and other matters so that we may all benefit from the work of each other.

References

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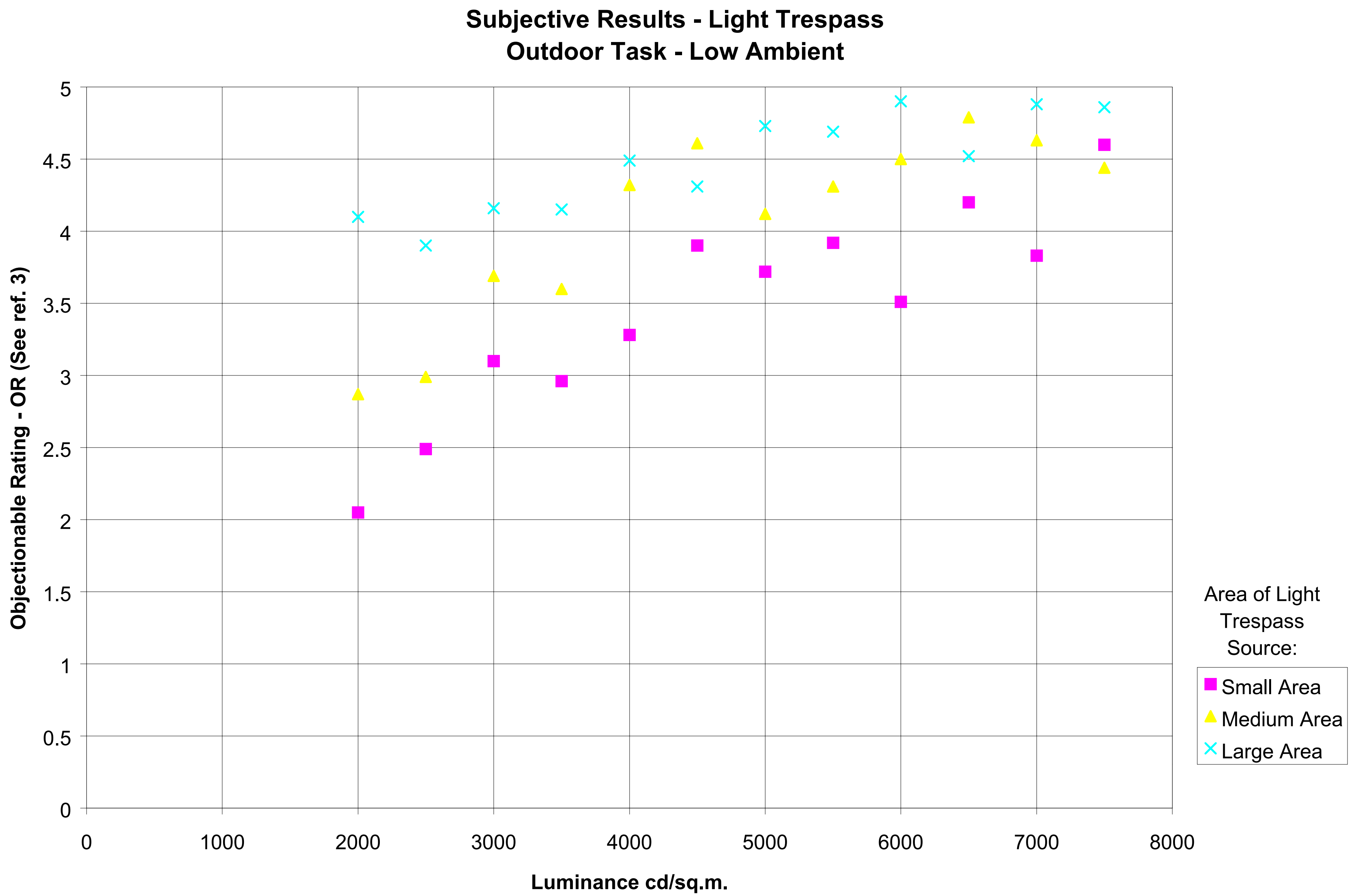
Subjective Results - Light Trespass
Outdoor Task - Low Ambient
Objectionable Rating - OR (See ref. 3)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
7000
8000
Luminance cd/sq.m.
Area of Light Trespass Source:
Small Area
Medium Area
Large Area

Figure 4