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## ***White Paper on Unified Glare Rating (UGR)***

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Luminaire Section

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## Foreword

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## Introduction

The Unified Glare Rating (UGR) is one of a few lighting metrics that lighting design practitioners utilize to model and design appropriate lighting to meet application and task visual needs. In the hands of a competent lighting designer, UGR can provide insight into visual comfort expectations to be included in a complete lighting design because it incorporates the room layout, luminaire layout, task being performed, surface reflectances, etc. However, improper use of the UGR approach can result in poor lighting design, poor luminaire design, and unintended glare.

This white paper aims to prevent such misuse through education on the context of UGR and by demonstrating how erroneous use as a luminaire-specific qualification metric can lead to glare inaccuracies for lighting designs.

Three new terms are used in this document for UGR:

- a. **UGR<sub>Appl</sub>**: Application UGR is the value obtained by full use of the International Commission on Illumination (CIE) method on the particular application (room shape, luminaire layout, luminaire parameters, tasks). (UGR<sub>Appl</sub> includes correct “averaging” of the relevant UGR<sub>Point</sub> values—see below.)
- b. **UGR<sub>Lum</sub>**: Luminaire UGR is the use of UGR to evaluate/compare luminaires in a single defined application (room shape, luminaire layout) when the luminaire may actually be used in many different applications.
- c. **UGR<sub>Point</sub>**: Point UGR is UGR calculated at a single point in a room—by simulation software, for instance.

Both UGR<sub>Point</sub> and UGR<sub>Lum</sub> are inappropriate uses of UGR for luminaire evaluation, as will be detailed below. UGR<sub>Lum</sub> does not consider the application and UGR<sub>Point</sub> is subject to error because no averaging is done.

This white paper will review the historical background, papers, and Standards on UGR<sub>Appl</sub> to clarify the intended use, embedded assumptions, and correct lighting design use. It will describe what can happen when the inadequate measures—UGR<sub>Lum</sub> and UGR<sub>Point</sub>—are used. It is expected that through this information, organizations and individuals will be more informed on UGR as well as its proper and improper uses. We also hope that it will lead to improved lighting designs.

### Comments for Design Professionals

Glare is difficult to address with a single metric because of the various factors that impact one's perception of glare. Issues such as age and the physiology of adaptation are key to shaping individual experience with and sensitivity to glare; studies have even shown that there is a link between caffeine ingestion and glare tolerance<sup>1</sup>! At a minimum, it is hoped that this white paper reiterates the importance of qualified lighting design to balance all of the factors, many of which may be in conflict, including task illumination, task uniformity, glare, application uniformity, vertical illumination, circadian impacts, architectural composition, visual interest, and many more than can be mentioned here.

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<sup>1</sup> M. G. Kent et al., “Temporal variables and personal factors in glare sensation,” *Lighting Research & Technology*, 48(6): 689-710, 2015, <https://journals.sagepub.com/doi/full/10.1177/1477153515578310>.

S. Altomonte et al., “Visual task difficulty and temporal influences in glare response,” *Building and Environment*, 95: 209-226, 2016,  
<https://www.sciencedirect.com/science/article/abs/pii/S0360132315301293>.

Before venturing into the details, several key overview points:

- a. CIE 117 is the primary document for understanding UGR. In the simplest terms, UGR is a formula that calculates the ratio of the luminance of all the light sources in comparison to the background luminance from all the surfaces of the room. This value can point a qualified professional to a single-number representation of glare expectation for a certain luminaire in a certain application.
- b. CIE 117 also includes a tabular method that is analogous to the Coefficient of Utilization (CU) tables, which were once commonly provided with luminaires to roughly approximate the average task plane illumination. It can be a helpful relative judgment of the average experience in an empty rectangular room with specific room ratios and reflectances.
- c. CIE 190 is one of the most referenced and misunderstood documents in recent publications. This document was created specifically to support the requirements of ISO 8995-1 (this is similar to the IES Illuminance Selection Procedure) but has recently been used to evaluate luminaires without consideration of the actual application. All luminaires are evaluated using a single room/luminaire layout from the CIE 190 tabular method, resulting in a  $UGR_{Lum}$  value. While it may be appealing because of its simplicity,  $UGR_{Lum}$  has extremely limited value because it does not include application factors and can be applied only as a relative comparison in one specific situation.
- d. CIE developed the UGR documents described in this white paper to address only interior spaces. (CIE 112, CIE 150, and ongoing work in several Standards organizations are related to approaches for exterior applications).
- e. CIE developed UGR to address only electric lighting, and it does not incorporate the impacts of daylight. Daylight Glare Probability (DGP) is a different approach utilized to evaluate daylighting concerns. While the two calculations attempt to arrive at the same prediction, there are significant differences, and both need to be used for a complete understanding.

The most important takeaway from this white paper is that  $UGR_{Appl}$  can provide an important piece of data to support a complete lighting design, while  $UGR_{Lum}$ , despite being attractive because of its appearance of simplicity, does not take into account the application. Therefore, its use in selecting products is discouraged.

The NEMA Luminaire Section encourages designers and customers to take the potential for glare into consideration during luminaire selection. When the situation can benefit from an understanding of UGR values, we recommend two approaches.

- a. First, the CIE 117 tabular method may be used (if the target space is a rectangular room with one regularly spaced luminaire type and no obstructions) to provide a general indication of UGR. This comes with assumptions and consequences that are explained in this paper.
- b. A second approach is to utilize simulation software to implement the full calculation of CIE 117, incorporating application specifics (room shape, luminaire placement, multiple luminaire types, room obstructions, room finishes, etc.). For situations where more complete application information is known, better assessment of the glare expectation of the occupants will increase significantly if multiple viewer locations are incorporated into the analysis. With either approach, the results should be judged as an approximation with a tolerance of  $\pm 3$  UGR units.

## I. The History and Intention of Application-Based Unified Glare Rating Calculations ( $UGR_{Appl}$ )

While the term “UGR” is common in today’s lighting vernacular, the history, limitations, and original intention of its use are not commonly understood. The primary development activities have been accomplished in the International Commission on Illumination (CIE) through a series of technical reports and Standards.  $UGR_{Appl}$  was originally developed to address lensed fluorescent troffers back in the late 1960s and early 1970s and has evolved over time.

Section I briefly summarizes the documents relevant to UGR. Detailed elaboration is given in the annexes.

### 1. CIE 117:1995 *Discomfort Glare in Interior Lighting—General Method*

CIE 117 defines  $UGR_{Appl}$  with the formula:

$$UGR = 8 \log \left[ \frac{0.25}{L_b} \sum \frac{L_s^2 \omega}{p^2} \right]$$

- a.  $L_b$  is the background luminance (represented by the illuminance at the eye excluding the direct light from the glare sources /  $\pi$ ).
- b. The summation contains factors for each light source within the field of view of the observer in the application. Each term includes:
  1.  $L_s$ : the average luminance of the light source in the direction of the observer (in practice: intensity / projected area)
  2.  $\omega$ : the solid angle of the light source at the eye of the observer (projected area / viewing distance squared)
  3.  $p$ : Guth position index (more discomfort results from sources closer to the line of sight)

CIE 117 limits the use of the formula. UGR is:

- a. For indoor lighting and electrical lighting design only
- b. For uniform background luminances
- c. Not for small light sources (subtending  $< 0.0003$  sr)
- d. Not for large light sources (subtending  $> 0.1$  sr)
- e. Not for indirect lighting

This CIE 117 general formula may be applied to rooms of any shape and luminaires in any arrangement. In addition, the document states that “one glare rating unit is the least detectable step and three glare rating units is an acceptable step in terms of glare criteria.” In other words, there is not an appreciable difference in expected glare between a space with a calculated result of  $UGR_{Appl}$  19 and  $UGR_{Appl}$  17, 18, 20, or 21. Conversely, calculations resulting in  $UGR_{Appl}$  19 and  $UGR_{Appl}$  16 would have a difference in the glare expectation.

### 2. CIE 117:1995 *Discomfort Glare in Interior Lighting—Tabular Method*

To simplify the calculations, the geometry of the room/luminaire configuration was standardized to rectangular rooms, regular planar arrays of  $n \times m$  asymmetrical identical luminaires (centered in the room with luminaire spacing  $S$ ), and locating the observer at the center of two orthogonal walls, viewing horizontally toward the center of the opposite wall, resulting in the CIE 117 “tabular method.” The tabular method was intended to enable easy comparison between different lighting situations.

Reflectances of floor, walls, and ceiling were limited to particular sets of values (see top section of Table A2 below). The dimensions of the room and the luminaire spacing are expressed in terms of  $H$ , which is defined as the vertical distance from the observer’s eye to the plane of luminaires. The observer is assumed to be sitting, with a floor-to-eye distance of 1.2 m.

The output is a table of  $UGR_{Appl}$  values, calculated for different room sizes, several sets of reflectances, and the two unique orthogonal observer locations at the centers of two perpendicular walls. Table A2 below is an example from CIE 117, calculated for a particular luminaire light distribution.

<b>Table A2 A typical uncorrected comprehensive UGR table.</b>													
Reflectances:		ceiling/cavity	0,7	0,7	0,5	0,5	0,3	0,7	0,7	0,5	0,5	0,3	
		walls	0,5	0,3	0,5	0,3	0,3	0,5	0,3	0,5	0,3	0,3	
		working plane	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	
Room dimensions:		Viewed crosswise					Viewed endwise						
x = 2H		y = 2H		14,4	15,4	14,6	15,6	16,0	13,5	14,5	13,7	14,7	15,1
		3H		14,3	15,3	14,6	15,5	15,8	13,3	14,3	13,6	14,5	14,8
		4H		14,2	15,1	14,5	15,3	15,6	13,2	14,1	13,5	14,3	14,6
		6H		14,0	14,8	14,4	15,1	15,4	13,0	13,8	13,4	14,1	14,4
		8H		14,0	14,8	14,4	15,1	15,4	13,0	13,8	13,4	14,1	14,4
		12H		14,0	14,8	14,3	15,0	15,4	13,0	13,8	13,3	14,0	14,4
4H		2H		14,4	15,3	14,7	15,5	15,8	13,6	14,5	13,9	14,7	15,0
		3H		14,3	15,1	14,6	15,3	15,7	13,4	14,2	13,7	14,4	14,8
		4H		14,1	15,0	14,5	15,2	15,7	13,2	14,1	13,6	14,3	14,8
		6H		14,1	14,7	14,6	15,1	15,6	13,2	13,8	13,7	14,2	14,7
		8H		14,0	14,6	14,6	15,0	15,5	13,1	13,7	13,7	14,1	14,6
		12H		14,0	14,6	14,6	15,0	15,5	13,1	13,7	13,7	14,1	14,6
8H		4H		14,0	14,6	14,6	15,0	15,5	13,1	13,7	13,7	14,1	14,6
		6H		14,0	14,5	14,5	14,9	15,3	13,1	13,6	13,6	14,0	14,4
		8H		13,9	14,3	14,4	14,7	15,3	13,0	13,4	13,5	13,8	14,4
12H		12H		13,9	14,3	14,4	14,6	15,3	13,0	13,4	13,5	13,7	14,4
12H		4H		14,0	14,6	14,6	15,0	15,5	13,1	13,7	13,7	14,1	14,6
		6H		13,9	14,3	14,4	14,7	15,3	13,0	13,4	13,5	13,8	14,4
		8H		13,9	14,3	14,4	14,6	15,3	13,0	13,4	13,5	13,7	14,4
Variations with the observer position at spacings:													
S = 1H		+0,9 / -2,1					+0,8 / -1,5						
1,5H		+2,2 / -7,9					+2,6 / -12,1						
2H		+4,0 / -16,0					+4,0 / -22,9						
Corrections for other luminaires of the same type:													
1 x 18W: +2,4		1 x 36W: 0					1 x 58W: -0,8						

The dimensions in the table are given in terms of H, the vertical distance from the observer's eye to the plane of luminaires. The tabular method is independent of the value of H if all relevant room dimensions are scaled consistently.

The  $UGR_{Appl}$  is obtained in the tabular method by setting the value of S/H to a seemingly unreasonable value, 0.25. However, the average UGR is independent of the value of S/H, and selecting a small value for S/H effectively averages the value of UGR.

Note: The smaller table beneath the main UGR table indicates the variation in  $UGR_{Point}$  that will result if a larger S/H ratio is chosen. See Annex A for details.

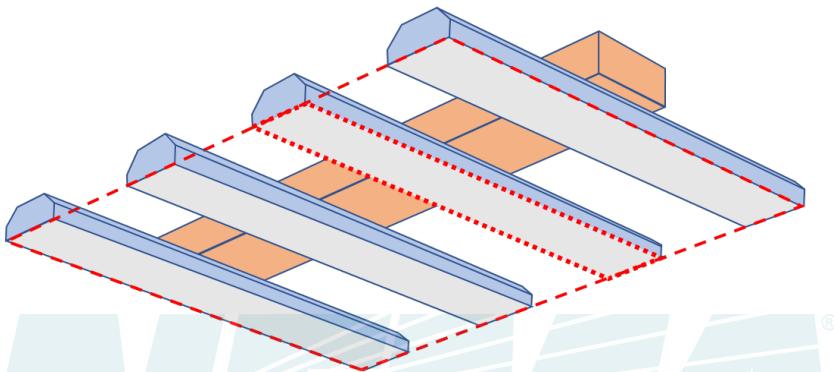
### 3. CIE 190:2010 Calculation and Presentation of Unified Glare Rating Tables for Indoor Lighting Luminaires

To facilitate comparison of results and to align with ISO 8995-1, CIE 190 uses the tabular method from CIE 117 but specifies that H is 2 m and S/H shall be 1:1. As described in Annex A, the choice of S/H = 1:1 is not optimal. Depending on the exact room geometry and the details of the luminaire light distribution (.ies file), the UGR calculated at the Standard observer position may vary by several points.

#### 4. CIE 232:2019 Discomfort Caused by Glare from Luminaires with a Non-Uniform Source Luminance

CIE 232 adapts the tabular method for use with luminaires having non-uniform luminance. This is of particular importance for LED luminaires, which may contain several light-emitting regions within the outline of the luminaire.

For example, the high bay luminaire below has four separate emitting areas (one is outlined in red dots), and luminance is not uniform over the entire luminaire surface (outlined in red dashes). UGR for this case will be incorrectly low if the luminaire is treated as if it were uniformly emitting across the large, red-dashed region. For such luminaires, the CIE 232 method basically calculates an effective source area that may then be used directly in the tabular method. For a luminaire such as that shown in the Figure 1 illustration below, this makes a difference of about 3 points in  $UGR_{Appl}$  calculated with the tabular method.



**Figure 1: Example of a luminaire with multiple emitting surfaces.**  
The emitting surfaces (one shown with dotted outline) should be used to calculate glare, not the outline of the entire luminaire (dashed outline).

## II. Common Utilization of UGR in Specifications and Requirements

A number of specification guides and voluntary requirements programs specify UGR limits.

### 1. Effective Incorporation of $UGR_{Appl}$

- ISO 8995-1:2002 *Lighting of work places — Part 1: Indoor*

This ISO Standard makes the most thorough use of  $UGR_{Appl}$ . With an extensive set of tables, it specifies maximum acceptable  $UGR_{Appl}$  for hundreds of different interior task areas and activities.

ISO 8995-1 adheres to the recommendations of CIE 117 that the minimum meaningful step for glare criteria is three glare rating units. All specified values are selected from the set of values: 13, 16, 19, 22, 25, 28. (UGR 13 is not used in the tables.) ISO 8895-1 makes proper use of application-based UGR, taking the entire application (luminaires, room, and tasks) into consideration, as intended by CIE 117.

- European Standard EN 12464-1:2011 *Light and lighting - Lighting of work places - Part 1: Indoor work places*

EN 12464-1 is similar to ISO 8995-1. It contains tables specifying maximum acceptable  $UGR_{Appl}$  for hundreds of indoor workplaces as part of establishing “lighting requirements...to meet the needs of visual comfort and performance of people having normal ophthalmic (visual) capacity.” Most of the entries are the same as in ISO 8995-1. EN 12464-1 makes proper use of UGR, taking the entire application (luminaires, room, and tasks) into consideration, as intended by CIE 117.

## 2. Problematic Use of UGR

### a. The DesignLights Consortium technical requirements v5.1

In the version 5.1 Technical Requirements, DesignLights Consortium (DLC) introduces a glare specification into their Solid-State Lighting program. It establishes individual luminaire  $UGR_{Lum}$  requirements for four of the six “General Applications”<sup>2</sup> (Troffers, Linear Ambient, Low-Bay, and High-Bay) in the Indoor Luminaires Category. (Reporting of BUG ratings is required for outdoor luminaires.) The  $UGR_{Lum}$  requirements are mandatory only for the “Premium” classification but may also be used for an efficacy allowance.

Problems include:

Although DLC has four different specifications on UGR, depending on luminaire type, no consideration is given to the actual application (room size, luminaire layout, task). DLC requires that the  $UGR_{Lum}$  calculation for the individual luminaire be done with a single room shape, 4H x 8H, 70-50-20 reflectances, and S/H = 1 (CIE 190 tabular method approach), regardless of the actual application. This results in  $UGR_{Lum}$ , not  $UGR_{Appl}$ .

### b. USGBC LEED 4.1 Interior Lighting—Indoor Environmental Quality Credit

The U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) version 4.1 includes Glare Control as one of the factors for consideration when pursuing the Indoor Environmental Quality Credits. Specifically, the requirements allow either the use of luminaires that have optical distribution characteristics that fall below particular values at particular angles or to “Achieve a Unified Glare Rating (UGR) rating of <19 using software modeling calculations of the designed lighting.” Although modeling may be done with the correct room shape, luminaire layout, and furniture, there are two problems with this approach:

1. A blanket UGR limit (19) is given that does not depend on the room use, bypassing the approach taken in ISO 8995-1 and ignoring the role of the tasks to be conducted in the rooms. This is not  $UGR_{Appl}$ , since it does not account for the room application.
2. Software modeling packages do not generally compute the  $UGR_{Appl}$ , instead reporting an array of  $UGR_{Point}$  values. It is up to the software user to select which of these values to report, or whether and which points to average. LEED 4.1 does not give instruction. (See Annex A).

### c. The WELL Building Standard (V2, feature L04)

The WELL Building requirements include limits on glare. Two options to qualify are provided, based on 1) “Luminaire considerations” or 2) “Space considerations.” Within each WELL option are two broad application areas, “Industrial” and “All Spaces except Industrial.” Each of the four option/application combinations has 1 to 3 requirements, one of which must be met to obtain the WELL points. In every option/application, UGR is one of the requirements. For both “Industrial” options, the limit is  $UGR = 19$  and for both “All Spaces except Industrial” options, the limit is  $UGR = 16$ . Wall wash concealed and decorative fixtures may be excluded. Little information is provided on the conditions (room layout, luminaire layout) to be used in the calculation of UGR. Verification is done by checking the luminaire specification sheets for option 1 and by checking a “modeling report” for option 2. Problems include:

1. Option 1 is based purely on the luminaire without taking the application into consideration. It uses  $UGR_{Lum}$ .
2. Option 2, similarly to LEED 4.1 discussed above, does enable inclusion of the actual room/luminaire/furniture layout, but does not change UGR limits based on the tasks conducted in the room and fails to explain that additional average analysis is required when utilizing simulation software.

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<sup>2</sup> The term “application” in DLC parlance means a luminaire type, and does not include room shape, luminaire layout, and task. The term “application” in this paper includes all of these parameters.

3. The requirement for manufacturers to write UGR<sub>Lum</sub> on a specification sheet is inappropriate because no application information can be supplied at the luminaire level. This can entrench the wrong use of UGR<sub>Lum</sub> in the industry.
- d. Considerations on the use of UGR
  1. UGR<sub>Appl</sub> has been standardized by CIE for international use. However, it is a complicated procedure; instructions for its use are spread over several CIE Standards and there are many opportunities for misinterpretation/misapplication.
  2. The approaches in CIE 117 were developed before computer simulations of lighting were common for every design situation. Present-day simulation software strives to replicate the intentions and approaches of the original requirements, while incorporating several decades of improvements in their field. Software simulations today can simply calculate the UGR<sub>Point</sub> for the actual room/luminaire layout, at many points within a defined region, and could combine those values over the correct region to produce the final UGR<sub>Appl</sub>; however, there are differences in the exact method used by each software package. The designer must pay close attention to the specific software documentation.
  3. It is not advisable to use UGR to predict acceptability or in any other way as an *absolute* measure of perception. UGR<sub>Appl</sub> may be used to estimate glare sensation, yielding *relative* comparisons; for example, if the light sources with the space are bigger, brighter, and closer to the observer, or if the light source is kept the same but evaluated in a darker environment, then it will create more glare than the same source without those conditions, and UGR<sub>Appl</sub> will indicate so. Confusion will result if absolute statements such as "70% of people experience glare discomfort" or "UGR 19 is acceptable glare" are used. It is impossible to make such statements without the complete context, and even then, there will be variations among individuals as to what is acceptable or not.

### III. Pitfalls and Considerations Required When Incorporating UGR into Design

UGR is frequently misused, either deliberately or accidentally, by not following the complete prescribed procedures from the CIE Standards. This can lead to misleading and unsubstantiated product claims and uncomfortable lighting conditions. Problems include:

1. UGR<sub>Lum</sub> does not ensure an acceptable, comfortable experience, when it is applied to the luminaire alone, without the context of the actual application (type of space, layout of luminaires, room surface reflectances, visual task/activity, arrangement of furniture and other visual obstructions, etc.). Even if the overall UGR<sub>Appl</sub> is calculated to be low, an individual may experience glare in some conditions. A person staring up at the ceiling will experience more glare, for instance. (Understandably, this geometry is not considered in the calculation of the UGR<sub>Appl</sub> tabular method, though it may be a relevant consideration in some applications, such as a person lying in a hospital bed.) ISO 8995-1 addresses this point by defining limits on application-UGR for many different applications.
2. UGR<sub>Lum</sub> limits on luminaires neglect application details that may result in the rejection of luminaires that are effective when used in a specific manner. For example, a wall washer may exhibit a high UGR<sub>Lum</sub> when evaluated in the mandated Standard condition, but when the primary direction of the luminaire is toward a wall in the application, it achieves a lighting designer's desired effect. Similar examples are of high-bay luminaires designed to illuminate warehouse boxes and labels that are evaluated as if they would be installed in an office and luminaires designed to be used in specific architectural expressions. By eliminating luminaires that may be perfectly acceptable or even preferable for an application, a UGR<sub>Lum</sub> specification removes options both for manufacturers and for designers.
3. The UGR<sub>Appl</sub> tabular method is based on uniform spacing of luminaires, in a rectangular empty room, and utilizing a single luminaire type. This may not be appropriate for some applications, where a full simulation can incorporate multiple fixture types, presence of partitions/furniture/shelving, non-rectangular fixture layouts, non-rectangular room geometry, and non-Standard user positioning.

4. Some qualification programs and specifications may require L- or UGR<sub>Point</sub> calculation with a single specified room/luminaire layout or with observer positions that are not the Standard positions. This may favor a certain product that happens to have a favorable L- or UGR<sub>Point</sub> value at those specific conditions.
5. Use of large S/H to calculate UGR<sub>Appl</sub> can give misleading values. The Standard observer position, in combination with the particular luminaire light distribution (.ies file), may yield a value of UGR<sub>Appl</sub> that is not close to the correct value (as explained in Annex A, and actually yields a UGR<sub>Point</sub> value). Depending on the exact conditions, even the value S/H = 1 used in CIE 190 may be too large for an accurate UGR<sub>Appl</sub>.
6. Manufacturers may report L- or UGR<sub>Point</sub> values on their datasheets, from a particular room/luminaire layout or observer positions that are not the Standard positions, selected to yield low L- or UGR<sub>Point</sub> values.
7. Light sources that have several small non-uniform emitting surfaces may be represented as if they are a single uniform emitting surface encompassing all the emitting surfaces together with non-emitting surfaces (Figure 1), which incorrectly reduces UGR<sub>Lum</sub>.
8. UGR simulations and calculations determine UGR<sub>Appl</sub> based on specific areas near the centers of two walls (see Annex A). These locations are expected to have the highest average UGR in the room when the room is rectangular, and the luminaire distribution is uniform (as assumed in the CIE tabular method). An observer at these locations, facing the opposite wall, will have the largest number of luminaires in view, and therefore would be expected to experience the highest glare from these positions (Figure 2). This may be appropriate for many applications, however, if the tasks performed in the room or the arrangement of the room prevents people from being in those positions of highest UGR—then the resulting UGR<sub>Appl</sub> may lead to incorrect conclusions about the glare probability in that room. This example shows the importance of including the application details when determining what appropriate limits are for UGR (as was done in ISO 8995-1). Additionally, this demonstrates the risks of using un-averaged UGR<sub>Point</sub> values generated in many simulations (see #12 below).



**Figure 2: Example room simulation where each data point is a UGR<sub>Point</sub> calculation for that location. The highest values of UGR<sub>Point</sub> are in the orange-colored region. (Orange indicates locations where UGR<sub>Point</sub> exceeds the UGR limit chosen for this particular simulation).**

9. The CIE 117 UGR generalized formula typically favors narrow optical distributions and fully indirect distributions over other types; however, a designer should not automatically rule out broader distributions as (s)he balances the different needs in the application. Relying on an overly narrow distribution can result in additional visual consequences such as the “cave effect” and non-uniform lighting of walls and task planes. These are elements that a full lighting design would be expected to incorporate.

10. Software vendors have implemented the parameters in the UGR calculation differently, and the details are generally proprietary. (See Annexes A and C for discussion of uncertainties in the UGR input parameters.) If a room is modeled with one software package, particularly in applications that vary greatly from the initial objective of troffers in a normal grid in an office or classroom, the resulting UGR values can vary between software packages.
11. Software packages produce a grid of  $UGR_{Point}$  values calculated at distinct points. They position the luminaires realistically for each particular design, but they generally do not calculate the  $UGR_{Appl}$  value, and the grid points may be too widely spaced to provide accurate averaging (see Annexes A and C).  $UGR_{Appl}$  may be misrepresented by picking one of the local  $UGR_{Point}$  values calculated by the software. When using software simulations,  $UGR_{Appl}$  should be calculated with a fine grid of points, within the Standard observer 1H x 1H square (see Annex A).
12. Daylighting evaluation utilizes an entirely different approach than  $UGR_{Appl}$  for electric lighting; therefore,  $UGR_{Appl}$  does not apply to daylighting or to evaluation of spaces with mixed daylighting and electric lighting. Daylight as a glare source frequently subtends an angle  $>0.1$  sr, is difficult to distinguish from the background luminance, is time-varying, and has a different relationship to our physiology.

### Conclusion: The Role of $UGR_{Appl}$ in Visual Comfort Estimation

Visual comfort is an important element of lighting design and luminaire selection. Unfortunately, how to capture/predict visual comfort in *absolute* terms is not clear.

Of the existing tools for glare, the  $UGR_{Appl}$  approach captured in CIE 117:1995 is the best approach to evaluate discomfort glare for electric lighting. However, it is a complicated procedure; instructions for its use are spread over several CIE Standards and there are many opportunities for misinterpretation/misapplication. The original objective of the CIE committee was to create a tool for *relative* evaluation, for use by lighting professionals, in the context of a complete design. The metric was not intended to be used as an absolute evaluation tool for a space nor for a luminaire without the context of the application. UGR is intended to be used in balance with other light quality measures, energy-efficiency principles, and considerations specific to the particular application, to design spaces that facilitate the comfort and productivity of the people present and the efficiency of the tasks conducted in the lit space.

In the hands of a competent lighting designer, simulations with commercial software packages<sup>3</sup> or, in appropriate circumstances, CIE's tabular method, incorporating the particular application details (luminaire spacing, room dimensions, tasks) can give valuable input on glare to a lighting design. UGR is one design parameter for lighting design that should be balanced with other design parameters, such as horizontal illumination, vertical illumination, color rendering, color temperature, temporal lighting artifacts, uniformity ratios, and human-centric objectives. Rigid limits on UGR, independent of the application, limit the options for designers to balance all the design parameters to achieve a desired end result.

NEMA Members are encouraged by the increased attention and are interested in collaborating on building the scientific understanding and implementation of measures to address visual comfort. It is critical to update our approach toward addressing visual comfort estimation calculations today with the current contemporary sources, form factors, application compositions, and design preferences.

To begin the process of improvements, the following are strongly recommended:

- a. Manufacturers should not present L- or  $UGR_{Point}$  values on specification sheets and marketing. In addition, voluntary qualification agencies such as DLC and WELL must refrain from requiring or requesting publication of luminaire-based UGR.
- b. Manufacturers may provide properly qualified and explained  $UGR_{Appl}$  values, including all assumptions such as room size, room reflectances, specific luminaires, and luminaire spacing.

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<sup>3</sup> Assuming that averaging of the  $UGR_{Point}$  values to obtain  $UGR_{Appl}$  is properly done. See Annex A.

They could provide either the CIE 117 tabular method table or simulation results with additional information, including the calculation grid and whether the reported value is properly averaged ( $UGR_{Appl}$ ) or single location ( $UGR_{Point}$ ).

- c. Organizations utilizing L- or  $UGR_{Point}$  should stop requiring/promoting this approach as a way to screen products with a number. As described above, visual comfort requires balancing many aspects of lighting design to achieve the objectives of the application. Hard limits on single metrics like UGR, without consideration of the application, unnecessarily limit the options for designers.



## Annex A: Technical Aspects of UGR

The purpose of this annex is to provide background on the technical aspects of UGR, particularly those aspects that may seem counterintuitive. The annex also explores cases where use of UGR is problematic. The purpose is not to exhaustively rewrite the CIE Standards on UGR. The reader is referred to the original documents for additional detail.

UGR, as calculated by the CIE tabular method, does not represent the worst-case glare observed in a space. Assumptions are made about the location of the observer (eye level at 1.2 m above the floor, located at the horizontal center of the walls) and the direction that the observer is looking (horizontally toward the opposite wall). The two chosen observer positions at the centers of orthogonal walls facing into the center of the room are generally the positions where the highest average UGR results. However, the exact local peak in UGR may not coincide with those defined positions and depends on the exact geometry of the room, the luminaire layout, and the light distribution from the luminaires. When UGR is correctly used (CIE 117 tabular method or simulation with proper averaging), the reported UGR is based on the *average* value of the quantity within brackets of Equation 1 over a 1H x 1H square located at the observer position.<sup>4</sup> If the observer position changes (either vertically or horizontally) or the direction of gaze changes, then the local UGR (defined as UGR<sub>Point</sub> below) will also change.

### 1. Definition of UGR

CIE 117 defines UGR as:

$$\text{UGR} = 8 \log \left[ \frac{0.25}{L_b} \sum \frac{L_s^2 \omega}{p^2} \right] \quad 1$$

where:

- $L_s$  is the average luminance of the light source in the direction of the observer (in practice: intensity / projected area, in cd/m<sup>2</sup>).
- $\omega$  is the solid angle of the luminous parts of a light source at the eye of the observer (projected area / viewing distance squared).
- $p$  is the Guth position index (more discomfort is produced by sources closer to the line of sight).
- $L_b$  is the background luminance (illuminance at the eye excluding the direct light from the glare sources / pi).

The summation is performed over all the luminaires in the room.

The equation is straightforward, but determination of some of its parameters is less straightforward. We now address each parameter in the calculation:

$L_s$ :  $L_s$  is defined as the intensity of the light source in the direction of the observer,  $I$ , divided by the projected area of the luminous parts of the light source in the direction of the observer,  $A_p$ .

$$L_s = \frac{I}{A_p} \quad 2$$

The intensity is obtained from the luminous intensity distribution of the luminaire (.ies file, in practice).

<sup>4</sup> The tabular method is equivalent to averaging the value within the brackets of Equation 1 over many points within the 1H x 1H square of Figure A-5. UGR is obtained from that average by applying 8 log to it. The averaging is described in detail in CIE PO150:2019 *Robust Unified Glare Rating Evaluation for Real Lighting Installations*. The average is not to be found by averaging the UGR values themselves. (CIE 117 uses the term “average” UGR to indicate that the tabular method does not result in an average of the UGR values themselves.)

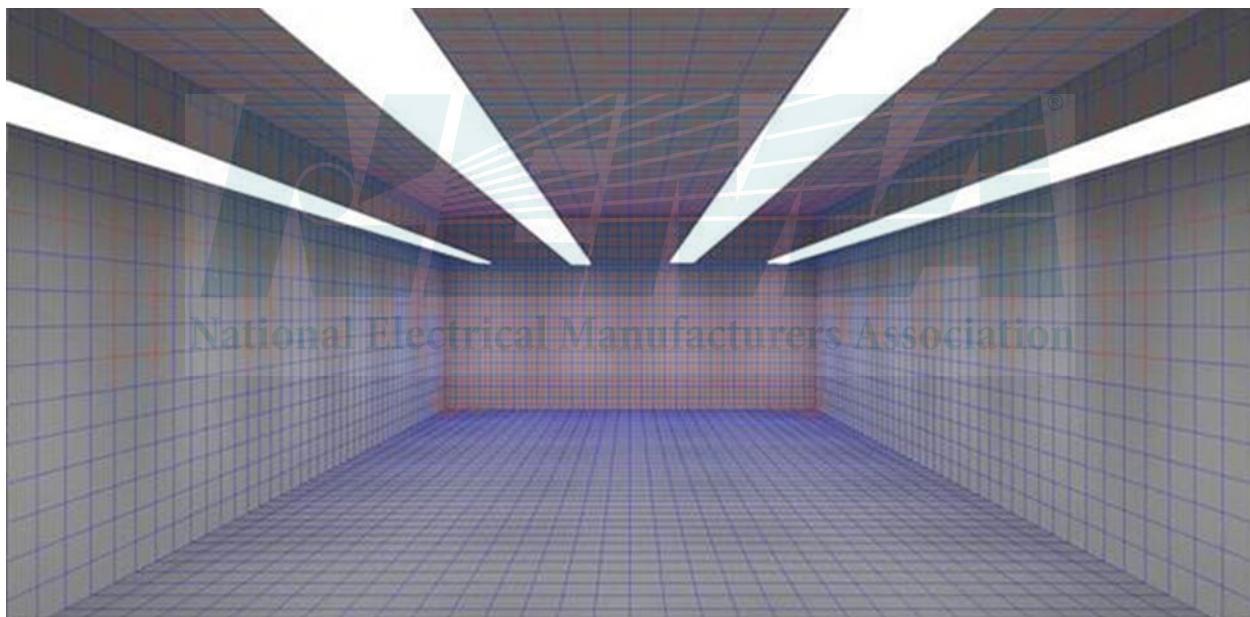
$\omega$ : The solid angle,  $\omega$ , is defined as the projected area of the luminous parts of the light source in the direction of the observer,  $A_p$ , divided by the squared distance from the luminaire to the observer,  $r$ :

$$\omega = \frac{A_p}{r^2} \quad 3$$

UGR is valid for  $0.0003 \text{ sr} < \omega < 0.1 \text{ sr}$ . (For example,  $0.0003 \text{ sr}$  is comparable to a circular downlight with luminous area having a radius of  $10 \text{ cm}$ , at a distance of  $10 \text{ m}$ .  $0.1 \text{ sr}$  is comparable to a luminaire with  $1 \text{ m}^2$  luminous area, at a distance of  $3 \text{ m}$ .)

p: Luckiesh and Guth,<sup>5</sup> using human subjects to study discomfort glare, derived a position index that describes the effect of displacement of a light source from the line of sight on glare. In general, discomfort is reduced as the light source is displaced from the line of sight, either horizontally or vertically. The position index also accounts for the shading effect of the human brow, eyelids, nose, and cheeks, which reduce glare from objects displaced vertically at high angles from the horizontal.

The solid angle in the case of the luminaire layout of Figure A-1 is larger than the  $0.1 \text{ sr}$  limit in the direction parallel to the luminaire long dimension. The Guth index is also not constant along the length of such an extended light source. Such a light source must be treated as several smaller luminaires in order to analyze it with UGR.



**Figure A-1: Schematic of a room with extended light sources.  
In order to use UGR, the luminaire must be split into a series of smaller luminaires.**

$L_b$ : The background luminance is probably the most complicated of the parameters. It is defined (CIE 117) as “that uniform illuminance of the whole surroundings which produces the same illuminance on a vertical plane at the observer’s eye as the visual field under consideration excluding the light sources.” Although the illuminance arriving at the observer’s eye in the actual application from different surfaces in the room will almost certainly vary, UGR makes the simplifying assumption that glare may be evaluated using this uniform background luminance, to contrast with the light from the luminaires.

Although CIE 117 describes three methods for determining the background luminance, all modern lighting design software (whether it uses the radiosity method with explicit surface subdivision or ray tracing and

<sup>5</sup> M. Luckiesh and S. K. Guth, “Brightnesses in visual field at borderline between comfort and discomfort (BCD),” Illum Eng. 1949, 44(11), 650-670.

photon mapping methods with implicit surface subdivision) uses the most general method described in CIE 117: "...the surfaces of the room are divided into sub-surfaces. The luminance of each of the sub-surfaces is determined from the direct illuminance from the luminaires and from interreflection between the sub-surfaces. Finally, the illumination of the eye of the observer produced by the sub-surfaces is determined."

CIE 117 also states: "UGR is relatively insensitive to errors in  $L_b$ ; for example, an error of +33% in  $L_b$  will result in an error of the UGR of 1 unit." ( $8 \log_{10}(1.33) = 0.99$ ). Thus, although  $L_b$  is simplified by assuming uniform background luminance, the consequences of the simplifying assumptions are expected to be small, in general. However, there are some situations where the variation in background luminance is great enough that UGR is of questionable value. For instance, some rooms may have light-colored walls with dark ceilings or vice versa, resulting in highly contrasting luminance from different surfaces (Figure A-2).



**Figure A-2: Unusual room decor where UGR is of questionable value.**

$A_p$ :  $A_p$  is defined as the area of the luminous emitting surface (with an implicit assumption that luminance is uniform over that area). Use of the outline of the luminaire instead of the luminous emitting surface area will incorrectly reduce UGR in some cases (Figure 1). CIE 232 addresses luminaires with non-uniform luminance. An incorrect definition of  $A_p$  has been used, for example, in the DesignLights Consortium's [UGR Resource](#).  $A_p$  is shown as the luminaire outline when several smaller light sources are within that outline.

## 2. Additional UGR Definitions

To distinguish between proper and incomplete/incorrect use of UGR, we define three additional UGR parameters.

**Application-based UGR ( $UGR_{Appl}$ ):** This is the UGR value calculated as intended by CIE 117 and elaborated on by CIE 232, if relevant. Limits placed on  $UGR_{Appl}$  should consider the tasks conducted in the room.  $UGR_{Appl}$  is to be calculated in one of two ways:

- a. The quantity within the brackets of Equation 1 is calculated at many observer positions within each of two  $1H \times 1H$  squares centered along two orthogonal walls (see Figure A-7) with the observer viewing horizontally toward the opposite wall and averaged for each square. UGR is calculated for each  $1H \times 1H$  square, by taking  $8 \log$  of each averaged value.  $UGR_{Appl}$  is the higher of the two UGR values thus obtained. Alternatively, if the software outputs a grid of UGR values calculated at individual points,  $10^{(UGR_{Point}/8)}$  may be averaged over each of the two  $1H \times 1H$  squares. Then,  $UGR_{Appl}$  equals  $8 \log$  of the higher of the two averages.
- b. The tabular method is used with a small S/H ( $S/H = 0.25$ ) and the UGR calculation is done at the user positions at the centers of the two orthogonal walls. The small S/H value effectively gives the

average UGR with a calculation at a single observer position. If a room is not well approximated by the tabular method (non-rectangular room shape, non-uniform luminaire layout, multiple luminaire types, etc.), then a) should be used.

**Luminaire-based UGR ( $UGR_{Lum}$ )**: This is the UGR calculated without including the actual application. A Standard room size and luminaire layout is chosen. The tabular method (either CIE 117 or CIE 190) is used to calculate  $UGR_{Lum}$ .

**Point UGR ( $UGR_{Point}$ )**: A software modeling package generally includes details from the application (room shape, luminaire layout, furniture, etc.) and calculates UGR at an array of points in the room. These values calculated at the local points are  $UGR_{Point}$  values. The individual values should be combined as described above to obtain the  $UGR_{Appl}$ .

Both  $UGR_{Point}$  and  $UGR_{Lum}$  are inappropriate uses of UGR, as will be detailed below.  $UGR_{Lum}$  does not consider the application and  $UGR_{Point}$  is subject to error because no averaging is done.

### 3. Dimensions (Mounting Height, Luminaire Spacing, etc.)

The tabular method from CIE 117 is a simplified method used for rectangular rooms and regular planar arrays of asymmetrical luminaires centered in the room, with the observer positioned at the center of the wall viewing horizontally toward the center of the opposite wall. A schematic diagram of a room where the tabular method may be applied is given in Figure A-3.

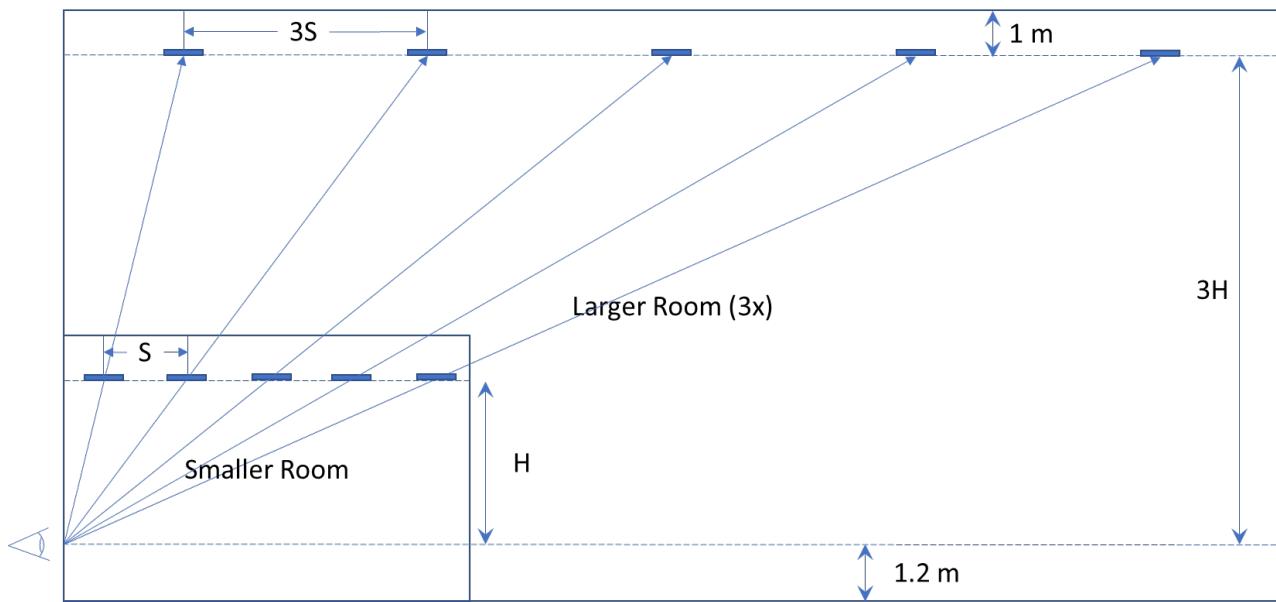
H: In the tabular method, all distances (room length, room width, and luminaire spacing) are given in terms of H, the vertical spacing between the plane of luminaires and the horizontal plane containing the observer's eye,  $H$ .<sup>6</sup> If all of these dimensions are scaled proportionally,  $UGR_{Appl}$  is independent of H (see Figure A-3). The distance from the observer's eye to the floor and any distance from the plane of luminaires to the ceiling do not have a significant effect on  $UGR_{Appl}$  as long as the reflectances of the floor-eye cavity and the luminaire-ceiling cavity are used in the calculation and not simply the floor and ceiling surface reflectances.

It may seem instinctively incorrect, for  $UGR_{Appl}$  to remain constant when the room dimensions change, but the same luminaires are present. The total amount of light in the room is the same, but the light levels will increase if the room is made smaller. Consequently, it may seem that glare should increase.

The relative positions of the luminaires remain the same when the room is scaled (Figure A-3).

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<sup>6</sup> H is often mistaken to be the height of the room.



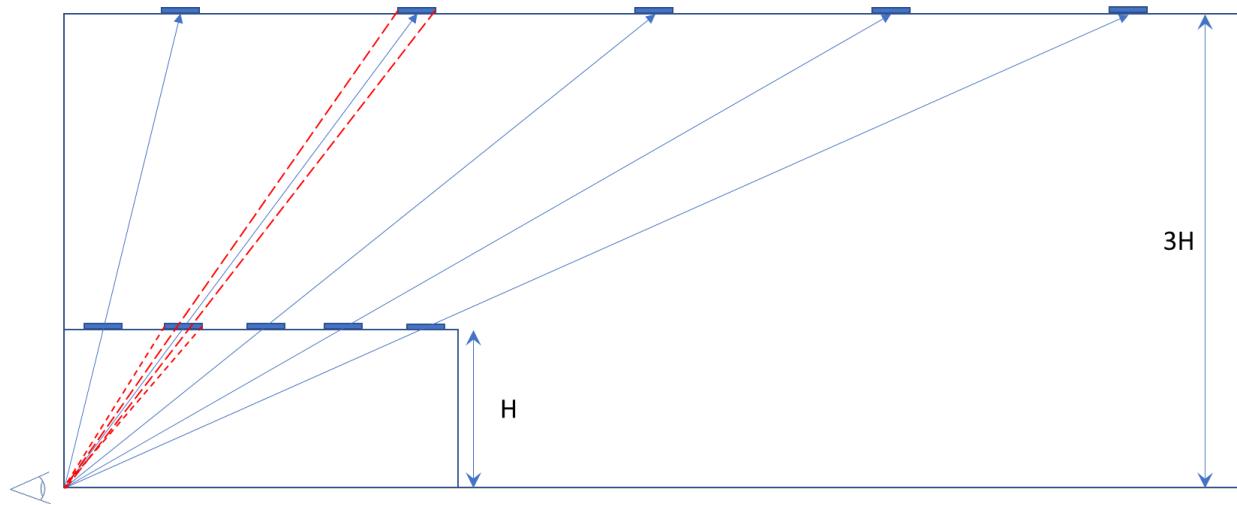
**Figure A-3: Layout of two rooms with different values of  $H$  but yielding the same A-UGR.  
(The depth dimension is also scaled with a factor of 3.)**

**The floor-to-eye distance and the distance from the luminaire plane were not scaled.**

**Rays drawn from the eye to the five luminaires show that the luminaire angular positions with respect to the observer's eye do not change.**

The solid angles of the luminaires change when the room is scaled, because the apparent sizes of the luminaires change from the observer's point of view (Figure A-4). The solid angles are proportional to  $1/H^2$  (Equation 3).

National Electrical Manufacturers Association



**Figure A-4: The solid angle of the luminaire, viewed from the position of the eye, decreases when room size is scaled upward. The angle between the two longer dashed lines (larger room) is smaller than the angle between the two shorter dashed lines (smaller room).**

The total amount of light generated in the room is the same in each of the two cases. (The exact same luminaires are present in both rooms.) But the distances all change, so the illuminance entering the eye from every direction decreases, according to  $1/r^2$ . The background luminance will also decrease by  $1/H^2$ , therefore.

The changes in solid angle cancel out the changes in background luminance, and  $UGR_{Appl}$  remains constant when the dimensions are equally scaled. There is a limit to the amount of scaling that can be done, however. If  $H$  is decreased, then the luminaire moves closer to the eye and appears larger. If  $H$  decreases by too much, the luminaire can get to be so large in the field of view that it goes outside of the range where  $UGR_{Appl}$  is considered valid ( $UGR$  doesn't apply to a large source, with solid angle  $> 0.1 \text{ sr}$ ).

Similarly, if  $H$  increases, then the luminaire gets farther away and appears smaller. If  $H$  increases by too much, then the luminaire can become so small in the field of view that it goes outside of the range where  $UGR_{Appl}$  is considered valid ( $UGR$  doesn't apply to a small source with solid angle  $< 0.0003 \text{ sr}$ ).

If  $UGR$  cannot be used for some of the sources present in a space because of too large/small solid angle, it does not mean that they do not cause glare!  $UGR$  calculated for such a space may underestimate the actual experience of glare in the space if these luminaires are ignored. Similarly, if they are not ignored, but treated as if  $UGR$  does apply,  $UGR$  calculated for such a space may overestimate the actual experience of glare in the space.

S/H: In the tabular method, the spacing between luminaires (assumed to be equal in each of the two orthogonal directions), S, is given in terms of  $H$ .

Instinctively, one might expect that increasing the number of luminaires, and therefore the total amount of light, could only increase the glare. However, glare is determined by the contrast of the light from the glare sources with the background. If  $S/H$  is halved, then the number of luminaires in the room quadruples. The background luminance also quadruples. The change in the number of luminaires cancels out the change in the background luminance, yielding no change in  $UGR_{Appl}$  from Equation 1.

However, although Equation 1 indicates that there is no change in  $UGR_{Appl}$  if  $S/H$  decreases, the variation in  $UGR_{Point}$  does change. CIE 117's tabular method produces tables such as the examples in Figures A-5 and A-6. (An "uncorrected" table is calculated with a luminance of 1000 lm for each luminaire. A "corrected" table uses the actual luminance of the luminaire, and results in a modification to the uncorrected table entries:  $UGR(\text{corrected}) = UGR(\text{uncorrected}) + 8 \log_{10}(L/1000)$ .)

The section of the tables headed by “Variation of the observer position for the luminaire distances S” shows the variation in  $UGR_{Point}$  that would result if the observer position were moved about within a 1H x 1H region at the nominal observer position at the center of the wall (within the green areas in Figure A-7). For Figure A-5, with  $S = 1.0H$  luminaire spacing, the (crosswise)  $UGR_{Point}$  given in the main part of the table will increase by 0.4 at the observer position with highest local  $UGR_{Point}$  and will drop by -0.4 at the observer position with lowest local  $UGR_{Point}$ . (The local  $UGR_{Point}$  will take on all values in between, too, depending on exactly where the observer is positioned within that 1H x 1H square.) If the luminaire spacing is changed to  $S = 2.0H$ , then the variation in  $UGR_{Point}$  increases, to as much as 1.9 above and 1.1 below the main table entry.

The amount of variation depends strongly on the luminaire light distribution. The luminaire of Figure A-6 yields larger variation of  $UGR_{Point}$  within the 1H x 1H region. At  $S = 1.0H$ , the local (crosswise)  $UGR_{Point}$  may be as much as 3.2 above or 3.1 below the main table entry in the endwise direction. In contrast to the luminaire of Figure A-5, this luminaire also has a different distribution in the two orthogonal directions, causing the variation at the crosswise position to differ from that at the endwise position. Local  $UGR_{Point}$  variation in the endwise position is +2.8/-2.6.



Glare Evaluation According to UGR													
p Ceiling	70	70	50	50	30	70	70	50	50	30			
p Walls	50	30	50	30	30	50	30	50	30	30			
p Floor	20	20	20	20	20	20	20	20	20	20			
Room Size		Viewing direction at right angles to lamp axis					Viewing direction parallel to lamp axis						
X	Y	2H	3H	4H	6H	8H	12H	2H	3H	4H	6H	8H	12H
2H	2H	19.7	20.6	20.0	20.8	21.0	21.7	19.7	20.6	20.0	20.8	21.0	21.0
	3H	20.8	21.6	21.1	21.8	22.1	21.7	20.8	21.6	21.1	21.8	22.1	22.1
	4H	21.2	22.0	21.5	22.3	22.5	21.6	21.2	22.0	21.5	22.3	22.5	22.5
	6H	21.6	22.3	21.9	22.6	22.8	21.6	21.6	22.3	21.9	22.6	22.8	22.8
	8H	21.7	22.4	22.0	22.6	23.0	21.7	21.7	22.4	22.0	22.6	23.0	23.0
	12H	21.7	22.4	22.1	22.7	23.0	21.7	21.7	22.4	22.1	22.7	23.0	23.0
4H	2H	20.2	20.9	20.5	21.2	21.5	20.2	20.2	20.9	20.5	21.2	21.5	21.5
	3H	21.4	22.1	21.8	22.4	22.7	21.4	21.4	22.1	21.8	22.4	22.7	22.7
	4H	22.0	22.6	22.4	22.9	23.3	22.0	22.0	22.6	22.4	22.9	23.3	23.3
	6H	22.5	23.0	22.9	23.3	23.7	22.5	22.5	23.0	22.9	23.3	23.7	23.7
	8H	22.6	23.1	23.1	23.5	23.9	22.6	22.6	23.1	23.1	23.5	23.9	23.9
	12H	22.7	23.1	23.2	23.5	24.0	22.7	22.7	23.1	23.2	23.5	24.0	24.0
8H	4H	22.2	22.7	22.7	23.1	23.5	22.2	22.2	22.7	22.7	23.1	23.5	23.5
	6H	22.8	23.2	23.3	23.6	24.0	22.8	22.8	23.2	23.3	23.6	24.0	24.0
	8H	23.0	23.3	23.5	23.8	24.2	23.0	23.0	23.3	23.5	23.8	24.2	24.2
	12H	23.2	23.5	23.7	23.9	24.4	23.2	23.2	23.5	23.7	23.9	24.4	24.4
12H	4H	22.3	22.6	22.7	23.0	23.5	22.3	22.3	22.6	22.7	23.0	23.5	23.5
	6H	22.9	23.1	23.3	23.6	24.1	22.9	22.9	23.1	23.3	23.6	24.1	24.1
	8H	23.1	23.4	23.6	23.8	24.3	23.1	23.1	23.4	23.6	23.8	24.3	24.3
Variation of the observer position for the luminaire distances S											National Electrical Manufacturers Association		
S = 1.0H	+0.4 / -0.4					+0.4 / -0.4							
S = 1.5H	+1.1 / -0.7					+1.1 / -0.7							
S = 2.0H	+1.9 / -1.1					+1.9 / -1.1							
Standard table	BK04					BK04							
Correction Summand	5.1					5.1							
Corrected Glare Indices referring to 25000lm Total Luminous Flux													

**Figure A-5: A representative A-UGR table, calculated with the tabular method of CIE 117. This is a “corrected” table, which means it was calculated using the actual luminance of the modeled luminaire. The possible variation in P-UGR is indicated in the lower portion of the table.**

Glare Evaluation According to UGR													
$\rho$	Ceiling	70	70	50	50	30	70	70	50	50	30		
$\rho$	Walls	50	30	50	30	30	50	30	50	30	30		
$\rho$	Floor	20	20	20	20	20	20	20	20	20	20		
Room Size		Viewing direction at right angles to lamp axis						Viewing direction parallel to lamp axis					
X	Y	2H	2H	20.4	21.1	20.6	21.3	21.5	20.3	21.0	20.5	21.2	21.4
		3H	20.6	21.3	20.8	21.5	21.7	20.6	21.3	20.9	21.5	21.8	
		4H	20.6	21.3	20.9	21.6	21.8	20.8	21.4	21.1	21.7	22.0	
		6H	20.7	21.3	21.0	21.6	21.8	20.8	21.4	21.2	21.7	22.0	
		8H	20.7	21.2	21.0	21.5	21.8	20.8	21.4	21.2	21.7	22.0	
		12H	20.6	21.2	21.0	21.5	21.8	20.8	21.4	21.2	21.7	22.0	
	4H	2H	20.3	21.0	20.6	21.2	21.5	20.2	20.9	20.5	21.1	21.4	
		3H	20.6	21.2	21.0	21.5	21.8	20.7	21.2	21.0	21.5	21.9	
		4H	20.8	21.3	21.2	21.6	21.9	20.9	21.4	21.3	21.7	22.1	
		6H	20.9	21.3	21.3	21.6	22.0	21.0	21.4	21.4	21.8	22.2	
		8H	20.9	21.2	21.3	21.6	22.0	21.0	21.4	21.5	21.8	22.2	
		12H	20.8	21.2	21.3	21.6	22.0	21.0	21.3	21.5	21.7	22.2	
	8H	4H	20.8	21.2	21.2	21.5	21.9	20.9	21.3	21.3	21.7	22.1	
		6H	20.9	21.2	21.4	21.6	22.0	21.1	21.3	21.5	21.8	22.2	
		8H	20.9	21.1	21.4	21.6	22.1	21.1	21.3	21.6	21.8	22.2	
		12H	20.9	21.1	21.4	21.5	22.0	21.1	21.3	21.6	21.7	22.2	
	12H	4H	20.8	21.1	21.2	21.5	21.9	20.9	21.2	21.3	21.6	22.0	
		6H	20.9	21.1	21.4	21.6	22.0	21.0	21.3	21.5	21.7	22.2	
		8H	20.9	21.1	21.4	21.5	22.0	21.1	21.3	21.5	21.7	22.2	
Variation of the observer position for the luminaire distances S													
$S = 1.0H$		+3.2 / -3.1						+2.8 / -2.6					
$S = 1.5H$		+5.6 / -3.4						+5.1 / -3.0					
$S = 2.0H$		+7.5 / -3.8						+7.0 / -3.5					
Standard table		BK01						BK02					
Correction Summand		2.7						3.2					
Corrected Glare Indices referring to 17000lm Total Luminous Flux													

**Figure A-6: A representative A-UGR table, calculated with the tabular method of CIE 117. This is a “corrected” table, which means it was calculated using the actual luminance of the modeled luminaire. This luminaire is more directional than the luminaire of Figure A-5, and therefore the local variation (lower section of the table) in  $UGR_{Point}$  is greater.**

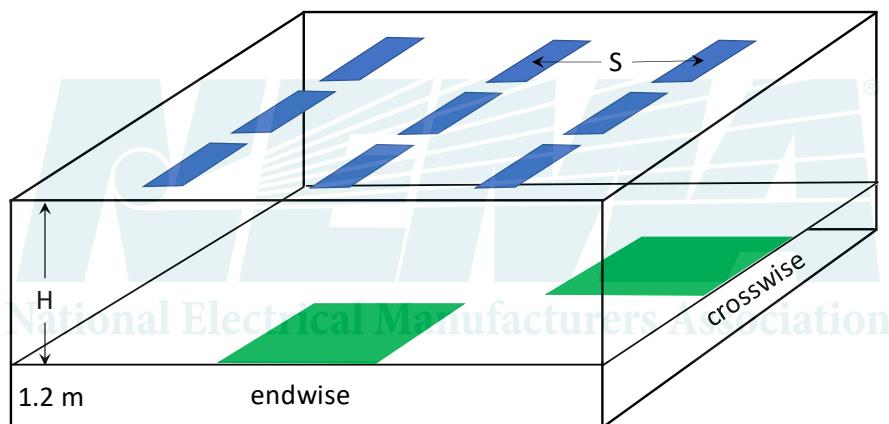
In both Figures A-5 and A-6 (and generally), the amount of local variation in  $UGR_{Point}$  decreases as  $S/H$  is decreased. For this reason, CIE 117 recommends calculating  $UGR_{App}$  with  $S/H = 0.25$ . Local variation of  $UGR_{Point}$  will be quite small at this luminaire spacing and a value close to the correct value will be obtained. This “trick” of setting  $S/H = 0.25$  allows  $UGR_{App}$  to be obtained with a single calculation (and the observer position at the designated points at the centers of the walls).

There is a risk if  $S/H$  is chosen to have a larger value than 0.25, and  $UGR_{Point}$  is calculated at only a single observer position (no averaging over the  $1H \times 1H$  (green) areas of Figure A-7), that the resulting  $UGR_{Point}$  will be substantially different from the  $UGR_{App}$ . This risk increases for more directional luminaires, designed to emit a larger fraction of their light at angles close to vertical. (These directional luminaires,

incidentally, are those that will have lowest [P-, L-, or A-] UGR.<sup>7</sup>) There is no guarantee that UGR calculated at the single observer position at the center of the wall will be close to the correctly calculated  $UGR_{Appl}$ , if S/H is large.

If an observer position is chosen outside of the  $1H \times 1H$  areas of Figure A-7, even larger variation in local  $UGR_{Point}$  than indicated by the tables (Figures A-5 and A-6) is possible. In the most extreme case, if the observer position is chosen to be near a wall and *facing* the wall, there will be no luminaires within the field of view, and  $UGR_{Point}$  will be at its minimum (10) regardless of which luminaire is present in the room see Figure A-8—values near the right side of the room).

The discussion above is based on CIE 117. CIE 190 limited the parameters for the  $UGR_{Appl}$  calculation, in an attempt to facilitate comparison of luminaires. H was fixed at 2 m and S was fixed at 1.0 H. The results of CIE 190 may be used for other values of H, because  $UGR_{Appl}$  is independent of H, if all relevant dimensions are scaled equally, as described above. The choice of  $S = 1.0 H$  is questionable, however.  $S = 0.25 H$  will yield a value closer to the  $UGR_{Appl}$ , as described above. The potential error in  $UGR_{Appl}$  is larger for  $S = 1.0$  than for  $S = 0.25$ . The amount of this potential error increases with luminaire directionality, making  $UGR_{Appl}$  uncertainty larger specifically for those cases where more directional luminaires are chosen with the design aim of low  $UGR_{Appl}$ . In effect, the UGR calculated by CIE 190 may be closer to a  $UGR_{Point}$  value than to  $UGR_{Appl}$ .



**Figure A-7: Schematic layout of a room for the CIE 117 tabular method. The blue shapes are the luminaires. The green shapes are the  $1H \times 1H$  regions over which P-UGR variation is calculated to get A-UGR. The height of the observer's eye above the floor is 1.2 m.**

#### 4. Lighting Design Software Packages for UGR Calculation

Several software packages calculate UGR for room layouts. It is not always clear how software packages handle the situations described in the preceding sections. For instance:

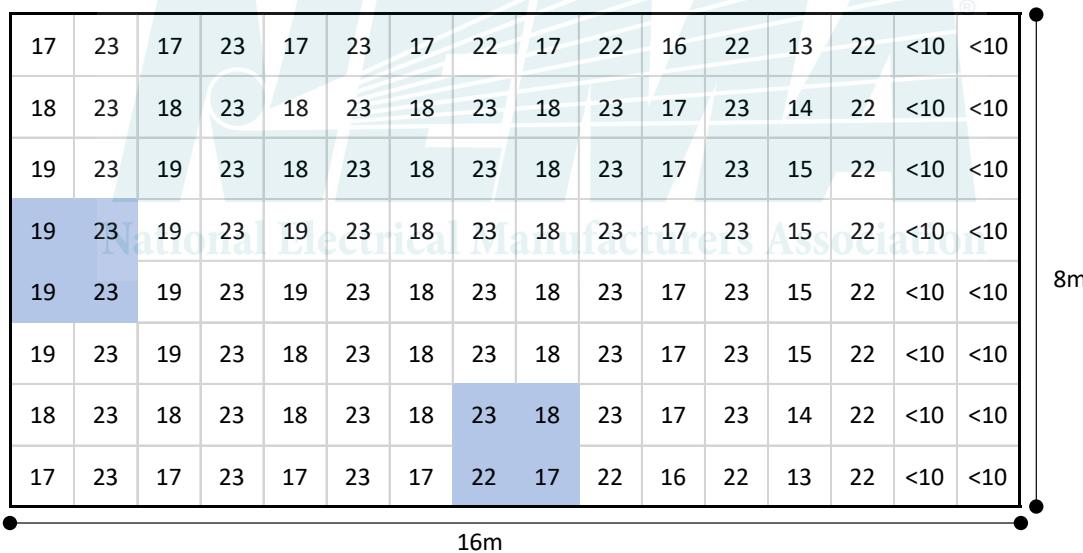
- If a particular light source exceeds the maximum solid angle (0.1 sr) or is below the minimum solid angle (0.0003 sr), what does the software assume? Does it ignore that luminaire? Does it

<sup>7</sup> To design luminaires yielding low UGR in a Standard calculation, it is generally necessary to tighten the beam, resulting in more downlight and less near-horizontal light. The optics that are used to shape the beam are generally pixelated, resulting in a less uniform appearance of the light emission (more “points of light”) when viewed from a distance. Tighter beams will also cause the light in the room to be non-uniform and will create “cave effect” on the walls. Adding more fixtures will reduce the resulting non-uniformity. There are thus undesirable consequences that must be considered when making a low-UGR specification.

communicate the assumption to the user? How is the resulting UGR affected by the assumptions in the software?

- b. Software packages generally calculate the local  $UGR_{Point}$  at a number of grid points defined within the room. (See example in Figure A-8.) How is the reported UGR determined from those local  $UGR_{Point}$  values? Is the point at the center of the wall used? Is the maximum chosen, and if so, is it chosen from the 1H x 1H square? Is any averaging done? If so, is averaging done over the values falling within the 1H x 1H areas (green areas in Figure A-7)? If an average is done, is the density of grid points sufficient to yield an accurate average over the 1H x 1H observer area? Is averaging done on the quantity within the brackets of Equation 1 or are the UGR values themselves averaged? (Most software packages do not calculate an average  $UGR_{Appl}$  but only provide  $UGR_{Point}$  values.)

In the example (Figure A-8), there are only four grid points within the 1H x 1H observer squares. The variation of the local  $UGR_{Point}$  over the two 1H x 1H observer (blue in Figure A-8) squares is 19-23. These will yield large variations in the reported UGR, depending on how the reported UGR is determined from the local  $UGR_{Point}$ . If the observer position is used at the edge of the walls, then reported  $UGR_{Point} = 19$ . If the maximum  $UGR_{Point}$  within the blue square is reported, it will be 23. If averaging is done, there are only four points in the 1H x 1H area—is this sufficient for an accurate average? Naively averaging the UGR values themselves yields  $UGR = 21$ . The correct average is  $8 \log(\sum(10^{UGR_{Point}}/8)) = 21.5$  (not a large difference from the naive average in this particular case). See also CIE PO150:2019. There is thus a large variation in the possible UGR reported for this space. When the calculation is repeated for the orthogonal direction, even wider variation may result.



**Figure A-8: Example of local  $UGR_{Point}$  results for a room, calculated for the observer facing to the right. The 1H x 1H area from CIE 117 is indicated with a shaded blue square. UGR is determined for the 1H x 1H square as  $8 \log(\sum(10^{UGR_{Point}}/8))$ . A second calculation is done for the observer facing toward the top of the page, and the observer position at the center of the bottom longer wall. The reported  $UGR_{Appl}$  is the higher of the two UGR values obtained (more than four values are desirable for a more accurate  $UGR_{Appl}$ ).**

## 5. Misconceptions About UGR

This section attempts to summarize some of the misconceptions about UGR. Elaboration on each of these can be found above.

- a. **“UGR is a product specification”**

UGR is an *application* specification but may be used to evaluate the quality of a luminaire and/or

compare luminaires for a particular application in a reference space. This is the approach taken in ISO 8995-1.

- b. **“A product with high UGR is always a bad product”**  
The usefulness of the luminaire depends on the application context. Each interior space, task, and activity has its own glare requirements and hence its own limiting value for UGR.
- c. **“UGR 19 means that the glare is acceptable to 65% of people”**  
Acceptability depends on context and cannot be strictly related to a luminaire specification.
- d. **“UGR 19 means that the discomfort glare by the luminaire is just acceptable”**  
Acceptability depends on context and cannot be strictly related to a luminaire specification.
- e. **“The UGR tabular method is relevant only for 2 m high ceilings”**  
The tabular UGR values are valid for any height H, as long as all relevant dimensions are scaled proportionally.
- f. **“The UGR tabular method is relevant only for a 2 m luminaire spacing”**  
The tabular UGR values are **average** values that hold for **any** luminaire spacing. Large luminaire spacings will lead to local deviations from the average UGR value. The magnitudes of these deviations are also indicated in the table.
- g. **“The UGR tabular method does not apply to my installation because the S/H ratio of 0.25 (or 1) does not match”**  
The small S/H is used for averaging only and has no effect on the average UGR value.
- h. **“A S/H ratio of 0.25 is not realistic and wrong because it is much too small”**  
The small S/H is used for averaging only and has no effect on the average UGR value.
- i. **“The old-fashioned tabular method should not be used because direct UGR calculations in modern software are more accurate”**  
Direct calculations may be unreliable if they do not calculate the correct average UGR value.
- j. **“UGR cannot be used for non-uniform luminaires”**  
CIE 232:2019 provides an addition to the UGR method in order to apply it to non-uniform sources in a reliable way.
- k. **“UGR cannot be used for LED luminaires”**  
This used to be true for bare LED arrays, but this has been addressed in CIE 232:2019.<sup>8</sup>

## 6. Final Remarks

UGR<sub>Appl</sub>, when used by a knowledgeable person, can yield useful design input on glare. It is one tool of many tools for lighting designers. But there are many misconceptions about its use and many opportunities for misuse. This annex provides supplemental information on the use of UGR, intended to facilitate proper use of UGR.

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<sup>8</sup> CIE 232 uses a high-dynamic-range camera to make luminance images of a light source. Filtering and calculation produce an effective emitting area for the luminaire. The measurements and calculation of the area are done by the manufacturer or a photometric laboratory, and the lighting designer simply enters the effective emitting area and uses UGR as before.

## Annex B: Understanding Human Factors Related to UGR

Physical discomfort caused by glare is still not well understood [1], but suggestions by some researchers claim reactions such as fluctuations in pupil size [2] and muscle tension around the eyes [3] may be responsible.

UGR, at its most fundamental definition, is a calculation-based metric recommending best practices for minimizing discomfort glare experienced by humans indoors. It is based on the British glare index system where 10 = just perceptible glare, 16 = just acceptable glare, 22 = just uncomfortable glare, and 28 = just intolerable glare. Here we look at the status of human subject research specifically as it relates to glare. We use this to illustrate the need for further studies while also highlighting some of the shortcomings in existing studies. Ultimately, we illuminate the disconnect between the numerical calculation of UGR and the human population it serves to benefit.

UGR and all other systems can be traced back to initial studies in the 1950s. One study in particular, carried out by Petherbridge and Hopkinson, attempted to quantify levels of discomfort glare in human subjects by exposing them to background light paired with glare sources [4]. Subjects then adjusted conditions until four predefined criteria of discomfort glare sensation were reached: Just Imperceptible, Just Acceptable, Just Uncomfortable, and Just Intolerable. This model and the conditions identified set the stage and influenced all subsequent glare models following, including UGR [5].

The research tying UGR (specifically) to perceived discomfort glare in humans is not extensive. Efforts to correlate subjective ratings from observers have been attempted. Only one such study was found. Akashi et al. [6] tested 61 observers, but even this study concluded that the results were contradictory. The main purpose was to obtain a correlation coefficient, for which they achieved a value of 0.95. This correlation coefficient was intended to show how well the UGR correlates to subjective glare rating.

At face value, the number looks promising. However, this study also concluded there was a strong bias showing that the mean subjective rating indicated less discomfort glare than predicted by the UGR values. Part of this bias could have arisen due to the following: When subjects were brought into the simulated office setting, they were not given any tasks to complete. They were exposed to a condition and expected to rate it. It is believed that subjects will rate exposure differently when performing a task versus not. In most real settings, a person in an office would be performing tasks. Thus, uncertainty of the accuracy of the method is mentioned in the study's conclusion, making it clear that further studies into correlation are needed to improve validity.

A study conducted on human subjects in 2013 by Sweater-Hickcox and colleagues using an LED array with a blue, white, and yellow luminous surround showed that both luminance and color of the immediate surround influence the human perception of discomfort glare [7]. While the UGR formulation considers background luminance, it does not account for any luminance immediately surrounding a glare source. It certainly does not account for windows or daylight, as is present in most buildings. Yet this study confirmed that this factor makes a difference.

Additional human subject studies on spectral power distribution (SPD) have found that higher correlated color temperatures (CCTs) increased discomfort glare perception [8, 9, 10]. These studies pre-dating those of LEDs using high-pressure sodium and high-pressure mercury lamps with different CCTs concluded that higher CCT values were found to be more discomforting for people, triggering the human glare response of the eye.

Current UGR measurements do not account for color temperature and spectral power distribution. This is yet another area that should be evaluated on a deeper level because it indicates that UGR does not fully accommodate the variables that influence the human perception of glare, which can also be influenced by external factors such as caffeine.

It is known with Daylight Glare Probability (DGP) that age and ethnicity also play a role in discomfort glare. In fact, this metric has a modifier to account for age. In regard to indoor glare, a study by Wolska and Sawicki in 2014 was conducted on elderly subjects 50+ years of age assessing their perception of

glare. These subjects were tested against adults younger than 35 years of age. All participants were tested in a laboratory that simulated an office environment where they were seated before a computer and asked to perform tasks. Results showed that discomfort glare changes with age [11]. The younger population was more sensitive and demanding than the older population.

It is also important to note that a recent study [5] by Kent et al. found that in a controlled laboratory experiment, adjustment tasks used to test the degrees of glare sensation from a bright light source are biased by the initial luminance setting (anchor). The anchor is defined as the initial light setting that a human subject is exposed to. As such, a number of glare studies on human factors should be reevaluated, specifically those that use low luminance settings as the anchor. One such aforementioned study conducted by Petherbridge and Hopkinson [4] falls into this category. And given that this study was the backbone for the development of subjective glare models we use today, one must question the alleged validity of the glare indexes used to describe the levels of discomfort due to luminous sources used today [5].

Given that UGR is a metric to improve quality of light indoors, its purpose is to serve human needs. Human subject research ought to be at the forefront of its development and adaptation. Yet there appears to be a fundamental lack of conclusive results regarding human subject research on UGR. With the existence of some 80+ experimental studies in various context, there exists no agreed-upon model for predicting the likely presence and/or severity of discomfort [12]. Much of this is due to a large variance in findings between subjects and studies.

In their recent 2020 paper addressing discomfort glare measurement, Fotios and Kent reviewed the wide breadth of studies and included over 80 citations to offer a great deal of insight as to where we stand on human subject tests. Most of the evidence gathered pointed to significant experimental bias in existing studies, furthering the questions: How well do we really understand discomfort glare as it pertains to humans and how qualified are we in implementing requirements based on scales that are derived from studies that have obvious bias? Their conclusion was insightful: "To date, the commonly used methods have failed to reach a consensus regarding the effects of glare on discomfort." This says a lot in how far we have yet to go in our quest to better understand UGR as a whole in how it affects humans.

Areas still in need of human-centric research include but are not limited to: correlation between subjective glare and UGR scales; color temperature; source area as it pertains to lighting type; age, gender, and ethnicity; and luminous surrounds. For example, a visually comfortable and uniform flat panel luminaire versus multiple bare LEDs spread over the aperture in context of a specific room and specific observers.

Furthermore, there is a lack of research indicating that UGR as a single-number representation is the best metric to drive lighting to a more human-centric solution. There is a risk that overreliance on any single-value representation of a relative metric will result in a decline of luminaire appearance, generating the dreaded "cave effect" seen in the fluorescent parabolic days of the 1980s.

The impacts on the occupants when sacrificing appearance and elegance in favor of a metric along with other factors such as vertical surface illumination and spectral factors should be specifically researched.

Finally, according to persons with knowledge of the original committees' intentions in general, it is not advisable to use UGR to predict acceptability or in any other way as an *absolute* measure of perception. UGR may be used to estimate glare sensation, yielding *relative* comparisons: if a source is bigger, brighter, and closer, or in a darker environment, then it will be glarier than the same source without those conditions, and UGR will indicate so. Confusion will result if absolute statements such as "70% of people experience glare discomfort" or "UGR 19 is acceptable glare" are used. It is impossible to make such statements without the complete context, and even then, there will be variations among individuals as to what is acceptable or not.

- [1] P. R. Boyce, *Human Factors in Lighting*, CRC Press, 2014.
- [2] G. A. Fry and V. M. King, "The Pupillary Response and Discomfort Glare," *Journal of the Illuminating Engineering Society*, 4(4): 307-324, 1975, DOI: 10.1080/00994480.1975.10748533.
- [3] S. M. Berman, M. A. Bullimore, R. J. Jacobs, I. L. Bailey, and N. Gandhi, "An Objective Measure of Discomfort Glare," *Journal of the Illuminating Engineering Society*, 23(2): 40-49, 1994, DOI:10.1080/00994480.1994.10748079.
- [4] P. Petherbridge and R. G. Hopkinson, "Discomfort Glare and the Lighting of Buildings," *Transactions of the Illuminating Engineering Society*, 15: 39–79, 1950.
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- [8] M. Sivak, B. Schoettle, T. Minoda, and M. J. Flannagan, "Short-Wavelength Content of LED Headlamps and Discomfort Glare," *Leukos*, 2(2): 145-154, 2013.
- [9] J. D. Bullough, "Spectral sensitivity for extrafoveal discomfort glare," *Journal of Modern Optics*, 56(13): 1518-1522, 2009, <https://doi.org/10.1080/09500340903045710>.
- [10] X. Zhu, S. Deng, M. Zhang, W. Cheng, and I. Heynderickx, "Perception study of discomfort glare from LED road lighting," *Light and Engineering*, 21(2): 61–68, 2013.
- [11] A. Wolska and D. Sawicki, "Evaluation of discomfort glare in the 50+ elderly: experimental study," *International Journal of Occupational Medicine and Environmental Health*, 27(3): 444-459, 2014, DOI:10.2478/s13382-014-0257-9, Epub 2014 Jun 21, PMID: 24952143.
- [12] S. Fotios and M. Kent, "Measuring Discomfort from Glare: Recommendations for Good Practice," *Leukos*, 4: 1-21, 2020, DOI:10.1080/15502724.2020.1803082.

## Annex C: UGR Computer Simulations

CIE 117:1995 *Discomfort Glare in Interior Lighting* defines a procedure for calculating the Unified Glare Rating (UGR) in an interior environment in accordance with the following equation:

$$UGR = 8 \log \left[ \frac{0.25}{L_b} \sum \frac{L^2 \omega}{p^2} \right] \quad 1$$

where:

$L_b$  is the background luminance ( $\text{cd}/\text{m}^2$ )

$L$  is the luminance of the luminous parts of each luminaire in the direction of the observer's eye ( $\text{cd}/\text{m}^2$ )

$\omega$  is the solid angle of the luminous part of each luminaire at the observer's eye (sr)

$p$  is the Guth position index for each luminaire (displacement from the line of sight)

Solving this equation is straightforward; the difficulty is in determining the parameters in accordance with CIE 117:1995.

### Background Luminance

CIE 117:1995 defines three separate approaches for calculating the background luminance:

1. Calculate the indirect utilization factor of the room walls in accordance with CIBSE Technical Memorandum 10 (TM10) *Calculation of Glare Indices*, 1985. This calculation assumes that "the average indirect illuminance on the walls more or less equals the indirect illuminance at the eye of the observer," noting that "This assumption works well for general lighting systems, with the luminaires in a uniform array."
2. Compute the luminances of the surface of the room. "The indirect illuminance at the eye of the observer is obtained by calculating the illuminance due to the walls as illuminants. This approach is slightly better than the first but still relies on the assumption that the room surfaces are uniformly illuminated."
3. Subdivide the room into subsurfaces and determine the luminance of each subsurface from the direct illuminance from the luminaires and from the interreflection between the subsurfaces. "The illumination of the eye of the observer produced by the subsurfaces is determined."

The third approach is used by all modern lighting design programs, whether they are based on the radiosity method with explicit surface subdivision or ray tracing and photon mapping methods with implicit surface subdivision.

As noted by CIE 117:1995, "The UGR is relatively insensitive to errors in  $L_b$ ; for example, an error of  $\pm 33\%$  in  $L_b$  will result in an error of the UGR of 1 unit." As an example, assume that the expression inside the square brackets of Equation 1 is 100; this will result in  $UGR = 16$ . If  $L_b$  is decreased by 33%, the expression becomes 150, and UGR becomes 17.4. (Quoting CIE 117:1995 again, "one glare rating unit is the least detectable step, and three glare rating units is an acceptable step in terms of glare criteria.")

It is important, however, to recognize the limitations of these background luminance calculation techniques, which rely on "the assumption that the room surfaces are uniformly illuminated." The underlying premise of Equation 1, and indeed all glare metrics, is that the luminous source is viewed against a background with constant luminance that fills the visual field. This implies that the UGR metric should not be applied to rooms with surfaces that have highly contrasting luminances, such as light-

colored walls with black ceilings or vice versa. It therefore depends on the judgment of the lighting designer whether a calculated UGR value makes sense for any given situation.

### Luminaire Luminance

The luminaire luminance  $L$  is given by:

$$L = \frac{I}{A_p} \quad 2$$

where  $L$  is the luminous intensity in the direction of the luminaire,  $I$  is its intensity in the direction of the observer, and  $A_p$  is the projected area in the intensity of the observer.

The difficulty is that IES LM-63 photometric data files technically represent only a single luminous box with the luminous sides *inside* the luminaire housing. Some LM-63 files use the luminous box height to represent the luminous sides of the luminaire, but this is incorrect and cannot be assumed for UGR calculations. Unfortunately, the majority of existing LM-63 files report zero dimensions for the luminous opening.

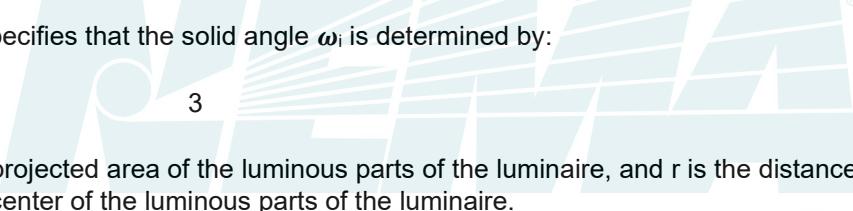
European EULUMDAT photometric data files have fields for luminous bottoms and four separate luminous sides, but there is no guarantee that this information will be included in a specific file.

### Solid Angle

CIE 117:1995 specifies that the solid angle  $\omega_i$  is determined by:

$$\omega_i = \frac{A_p}{r^2} \quad 3$$

where  $A_p$  is the projected area of the luminous parts of the luminaire, and  $r$  is the distance from an observer to the center of the luminous parts of the luminaire.

  $\omega_i$  is the solid angle of the  $i$ -th glare source of a circular disc with radius  $R$  viewed on-axis at a distance:

$$\omega_i = 2\pi(1 - \cos\theta) \quad 4$$

where  $\theta$  is the subtended angle  $2 * \text{atan}(R/d)$ .

Section 6, "Limitations of the UGR formula," of CIE 117:1995 specifies that  $0.003 \leq \omega_i \leq 0.1$ . From the approximate formula, the area of a disc with  $A_p = 1.0$  must vary between  $0.003$  and  $0.1 \text{ m}^2$ . Thus  $R = \sqrt{a/\pi}$ , and so  $0.031 \leq R \leq 0.178$ . Inserting these values into Equation 3, we have  $0.003 \leq \omega_i \leq 0.097$ . Thus, the worst-case difference between Equations 3 and 4 for  $\omega_i = 0.1$  is 3%.

Where Equation 3 may fail, however, is for a long linear luminaire approximately parallel to the observer's view direction. The Guth position index  $p$  changes along its length, and so it should be subdivided into sections that are considered as independent luminous parts of the luminaire.

### Guth Position Index

The Guth position index is tabulated in Table 4.1, "Table of position indices," of CIE 117:1995. An analytic approximation is available in:

R. E. Levin, "Position Index in VCP Calculations," *Journal of the Illuminating Engineering Society*, 4(2): 99-205, 1975, DOI: 10.1080/00994480.1975.10748496.

but it produces unacceptably inaccurate results for extreme displacements from the line of sight.

Figure 4.2 of CIE 117:1995 specifies that the position index ratios H/R and T/R are “based on the center of the luminaire,” but this contradicts Figure 4.1, which refers to the “luminous parts of the luminaire.” Calculating the Guth position index for a long linear luminaire approximately parallel to the observer’s view direction based on the center of the luminaire can produce highly inaccurate UGR values. As with solid angle, such luminaires should be subdivided into sections that are considered as independent luminous parts of the luminaire.

### Mounting Height

Section A.2.2, “Luminaire Layout,” of CIE 117:1995 states that:

“The UGR is independent of the mounting height, H, of the luminaires above the observer’s eye level. If a room and a lighting installation is expanded, so that the height, H, changes from  $H_1$  to  $H_2$ , the length and width of the room and the luminaire spacings change by the same proportion. In the UGR formula, the following terms change:

$$\omega_2 = \left(\frac{H_1}{H_2}\right)^2 \cdot \omega_1$$

$$L_{b2} = \left(\frac{H_1}{H_2}\right)^2 \cdot L_{b1}$$

where  $\omega$  is the solid angle of the glare sources and  $L_b$  is the background luminance, and  $L_b$  change because of the increase in distance to the luminaire and the increase in the size of the room, respectively.

The two changes cancel each other out in the UGR formula, so the height H does not directly influence the UGR.”

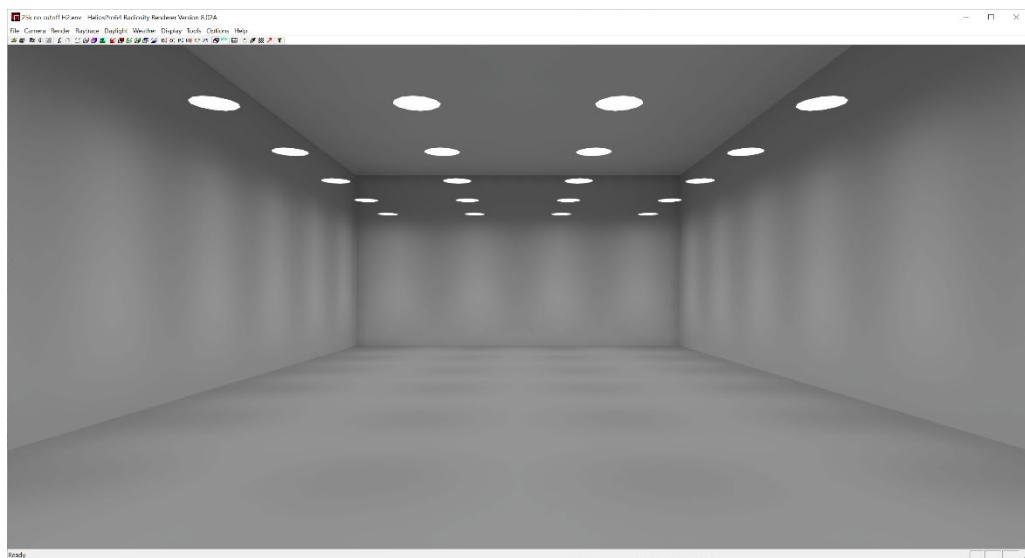
This is extremely misleading in stating that, “The UGR is independent of the mounting height, H.” *This is incorrect.* The key phrase here is, “the length and width of the room and the luminaire spacings change by the same proportion.” What is not stated here, but which is an essential point, is that the observer position must also be scaled accordingly.

The proper phrase is that the UGR is *scale-invariant*. It simply means that the UGR does not change if the room dimensions (including the luminaire mounting height and spacing, and the observer position) are scaled, but the luminaire dimensions remain constant.

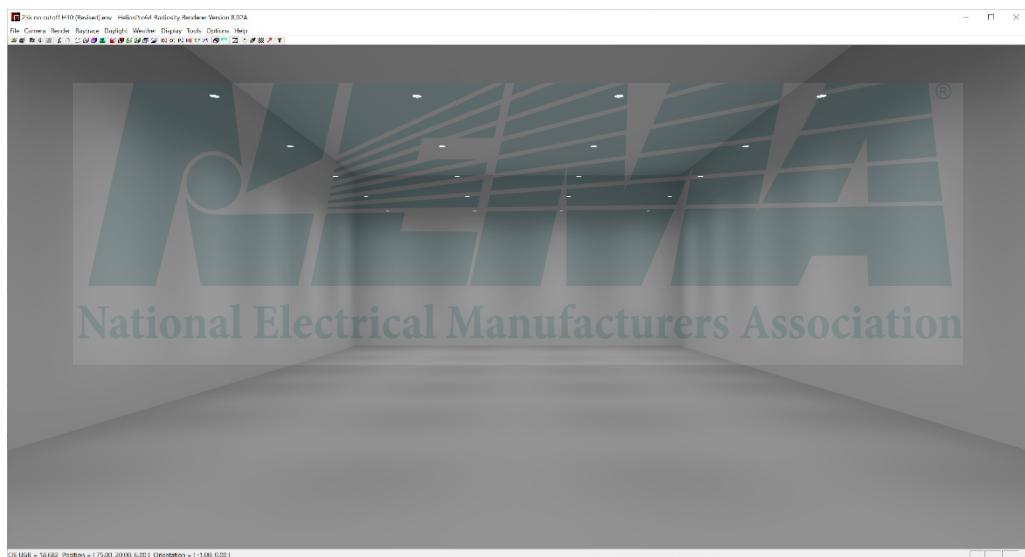
To demonstrate this, two geometrically identical rooms were modeled with 32 circular downlights as shown in Figures C-1 and C-2. Their dimensions are:

		Room C-1	Room C-2
Room	Length	16.0 m	80.0 m
	Width	8.0 m	40.0 m
	Height	4.2 m	21.0 m
Luminaire	Mounting Height	3.1 m	15.5 m
	Length	15.0 m	75.0 m
	Width	4.0 m	20.0 m
Observer	Height	1.2 m	6.0 m

In other words, the dimensions of Room C-2 (including the observer position) are five times those of Room C-1. The luminaire dimensions, however, are not scaled. Consequently, they appear to the observer to be smaller in Room C-2.



**Figure C-1: Empty rectangular room with dimensions 16.0 m L x 8.0 m W x 4.2 m H**



**Figure C-2: Empty rectangular room with dimensions 80.0 m L x 40.0 m W x 21.0 m H**

Four of the luminaires are directly above the observer position, and so only 28 luminaires are visible to the observer. If the minimum solid angle limit of 0.0003 steradians is ignored, the calculated UGR values are:

Room C-1: 23.48 (background luminance 285.59 cd/m<sup>2</sup>)

Room C-2: 23.37 (background luminance 11.64 cd/m<sup>2</sup>)

Note: The background luminance is determined by averaging the luminance of all elements visible within a 180° hemispherical view from the observer position.

The background luminance of the second room is 2% greater than that of the first room divided by the square of the scaling factor (i.e., 25). This is due to the reflectance of the luminaires, which in the two computer models is 1.0%. The smaller projected angles of the luminaires in the second room allow more of the background to be visible, which accounts for the difference in average background luminance. This similarly results in an unnoticeable difference of 0.1 units in UGR between the two rooms.

According to CIE 117:1995, however, the minimum solid angle limit of 0.0003 steradians **cannot** be ignored. Taking this into account results in starkly different UGR values:

Room C-1: 23.25 (8 luminaires less than 0.0003 sr)

Room C-2: 18.68 (26 luminaires less than 0.0003 sr)

Lighting design software programs do not provide detailed information on how UGR is calculated for a given situation, but the small solid angles of the luminaires in both Figures C-1 and C-2 offer a clue. In Room C-1, there are 8 luminaires whose solid angles are less than 0.0003 steradians, which accounts for the calculated UGR value going from 23.48 to 23.25. This is, of course, an insignificant change.

In Room C-2, there are 26 luminaires with solid angles less than 0.0003 steradians. This means that only two of the 28 luminaires (which are not visible in the rendering) are considered as contributing to glare, as opposed to 20 luminaires for Room C-1. The result is the calculated UGR value going from 23.37 to 18.68.

Room C-2 could reasonably represent a large warehouse design, where a difference of nearly 5 units could mean the difference between a design's being accepted or rejected. This highlights the need for lighting designers to be aware of the factors involved in UGR calculations, whether it is background luminance, luminaire luminous surfaces, or projected solid angles. Quoting an old Russian proverb, "Trust, but verify."

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