Light & Engineering
Vol. 26, No. 1, pp. 73-80, 2018

Svetotekhnika
No. 4, 2017, pp. 35–41

A SIMPLE METHOD TO IMPROVE VCP BY REDUCING DGR IN AN INTERIOR LIGHTING INSTALLATION

Madjidi Faramarz[1] and Abedi Kamal ad-Din[2,3]

[1] *Occupational health engineering department, Faculty of Health and Paramedical Sciences,*
Zanjan University of medical sciences, Zanjan, Iran
[2] *Environmental health research centre, Kurdistan University of medical sciences, Sanandaj, Iran*
[3] *Department of occupational health engineering, Faculty of health,*
Kurdistan University of medical sciences, Sanandaj, Iran
E-mail: kamal.abedi@gmail.com

ABSTRACT

Discomfort glare rating (DGR) and Unified glare rating (UGR) are main models currently used as discomfort glare evaluation systems, both of which are calculated employing four factors including the luminaire size, the luminaire position relative to the observer, background luminance, and the luminaires number and location. This study aims at proposing a simple solution for reducing DGR and thereby increasing visual comfort perception (VCP) in an interior lighting system. The proposed solution is based solely on variations of luminaire surface area without change in other factors, e.g. candlepower and number and location of luminaires in the lighting system. To this end, firstly, the equations related to DGR were modified for a desired luminaire, and, secondly, by solving the modified equations, the new luminaire surface area was obtained, which caused DGR decrease and VCP improvement. Finally, by some modifications in the location of selected luminaires having main role on DGR, the VCP rose considerably.

Keywords: DGR, VCP, Interior lighting, luminaire surface area

1. INTRODUCTION

Glare is a phenomenon known to the public; however, it is not easy to define in technical terms [1–4]. The Illuminating Engineering Society of North America (IESNA) defines glare as one of the two following conditions [5, 6]:

"1- Too much light; 2- Excessive contrast, i.e. the range of luminance in the field of view (FOV) is too great".

Although several measurement systems such as discomfort glare rating (DGR), unified glare rating (UGR), British glare index (BGI), Cornell glare index (CGI), predicted glare sensation vote (PGSV), discomfort glare probability (DGP), and visual comfort probability (VCP) have been developed, there is still need to validate the existing models or develop new reliable metrics [7–10].

To evaluate glare, light cannot be measured in lx or foot candles. Instead, it is luminance that has a great impact on glare, which typically is measured in candelas per square meter (cd m^{-2}) or nits in former time [6, 11, 12]. In practice, in a good lighting design either the light is diffusing within the space or the luminaire is enclosed or shielded from FOV to reduce the luminance [6, 13]. Reducing luminance results in DGR decline and subsequently VCP improvement [14]. The VCP value predicts the percentage of people who would be expected to find the lighting acceptable in terms of discomfort glare [13, 15]. Manufacturers provide VCP tables for most luminaires, which is specified for a person in a particular location looking horizontally in a specific direction. The room size, reflectance, fixture type and location, and the number of fixtures in FOV are all determining factors of VCP for interior lighting [5, 7, 10, 15–17].

In 1949, Luckiesh and Guth conducted a comprehensive study, which become the basis for the development of VCP index. They called the metric they developed in that study "borderline between comfort and discomfort" [18]. In 1963, Guth finally proposed a method for calculating DGR, after a decade of ongoing studies on discomfort glare, which was merged by the work of other scientists of this field and published by IESNA [19]. Despite many modifications and simplifications that have been carried out from 1963 to 2000, DGR and VCP still need to be improved [9, 20, 21]. The present study describes a method for VCP improvement by reducing DGR in interior lighting design only by changing the surface area of luminaires (the surface area of shielding of the light sources), without any modifications in the illuminations and arrangement of luminaires. To do this, a complete DGR calculation procedure for interior lighting design suggested by IESNA [1966–2000] and originally derived from Luchiesh and Guth's works, was employed [5]. The main objective of this study was to establish a direct relationship between index sensation (*M*) and luminaire surface area (*A*) for each luminaire so that by any changes in *A*, *M* and as a result DGR could be varied in a specific interior lighting installation. The paper will focus on mathematical procedures and discuss it in entire detail. The reason for choosing *A* is that making any change in the other variables leads to disruption in initial lighting design.

2. MATHEMATICAL PROCEDURES

The procedure outlined in this work for decreasing DGR in a room is essentially focused on the index sensation *M*, defined for one luminaire as below [5]:

$$M=\frac{L_s\,Q}{P\,F^{0.44}}, \tag{1}$$

where:

L_S is the average luminance of the glare source (laminaire) [cd/m^2],

Q is the function of visual size of the glare source,

P is the index of the position of the glare source with reference to the line of sight, which is calculated for any luminaire located in FOV,

F is the average luminance of the entire FOV [5, 15].

The average luminance, L_S, is calculated using the following equation [5]:

$$L_s=\frac{I}{A}, \tag{2}$$

where:

I is the luminous intensity [cd],

A is the luminaire surface area (shielding surface area) observed by the viewer,

P is also created from the Guth's experiment [22], which is given by the formula [5, 16]:

$$P=\exp[(35.2-0.31889\alpha-1.22e^{-2\alpha/9})10^{-3}\beta+ \\ +(21+0.26667\alpha^2)10^{-5}\beta^2], \tag{5}$$

where:

α is an angle from vertical line of the plain containing the luminaire and the line of sight shown in Fig. 1, β is an angle between the line of sight and the line from the observer to the luminaire (*D*) shown in Fig. 1,

Furthermore, both *Q* and *F* in Eq.1 are expressed in terms of solid angle subtended at the eye by each luminaire, ω_S, which are calculated as below [5, 7, 21, 23]:

$$Q=20.4\omega_s+1.52\omega_s^{0.2}-0.075, \tag{4}$$

$$F=\frac{1}{5}[L_w\omega_w+L_f\omega_f+ \\ +L_c(\omega_c-\sum_{i=1}^{N}\omega_s)+\sum_{i=1}^{N}L_s\omega_s], \tag{5}$$

where:

L_W is wall cavity luminance, L_f is floor cavity luminance, L_c is ceiling cavity luminance, ω_c is the solid angle subtended by ceiling.

Also, the solid angle subtended by each luminaire is equal to [5]:

$$A=\frac{\omega_s}{(V/D^3)}, \tag{6}$$

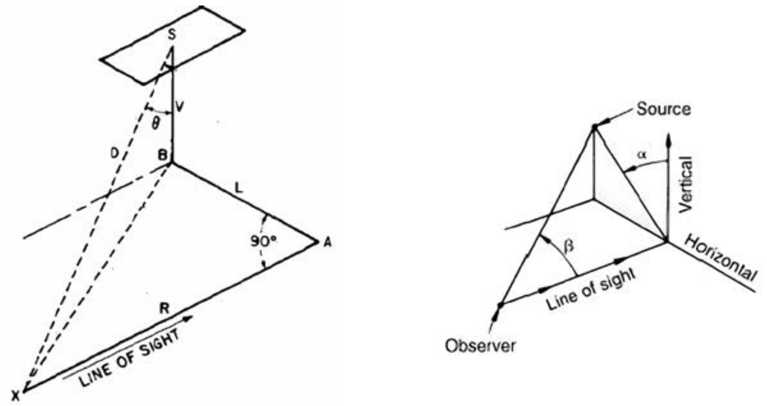

Fig.1. Geometric positions of the observer and luminaire as used in VCP calculations with courtesy of IESNA [1966 & 2000]

where:

V is the direct distance from observation point to centre of luminous area, D is the direct distance from observation point to photometric angle from nadir (shown in Fig.1.).

The Discomfort Glare Rating, *DGR*, is after all defined as [5, 7, 8]:

$$DGR = \left(\sum_{i=1}^{N} M_i\right)^{N^{-0.0914}}, \tag{7}$$

where;

M is the sensation index, N is the number of luminaires in the FOV.

The first issue is to determine how M varies with ω_s (or A). If we consider that the interior lighting system has only one luminaire, *e.g.* Luminaire No.1 in Guth's experiment [22] and putting the values Ls=138 and P=1.62 into the Eq.1, the sensation index of the luminaire No.1 (M_1) can be calculated as [5, 7, 24]:

$$M_1 = \frac{138(20.4\omega_s + 1.52\omega_s^{0.2} - 0.075)}{1.62 \times \frac{1}{5}[52.8 + 85.8 + 38.35(1.496 - \omega_s) + 138\omega_s)]}. \tag{8}$$

Plot of M_1 versus ω_s is shown in Fig. 2. As can be seen from Fig. 2, *M1* is an ascending function when $\boldsymbol{\omega_s} > 0$, meaning that it also rises with the luminaire surface area (shielding surface area), A, which is proportional to its ω_s. Likewise, the decrease of A will lessen the amount of M, and consequently results in a DGR decline. On the other hand, the decrease of A causes an increase of the glare source luminance (according to Eq. 2), leading to M rising otherwise. To overcome this inconsistency, all of the photometric characteristics of luminaires especially the intensity of luminaire should remain unchanged, excepting A, as has been emphasized in this study. Therefore, for two conditions specified as OLD and NEW, representing before and after applying modifications in the lighting system, the Eq. 2 can be rewritten under the assumption that the light intensities of all luminaires are equal:

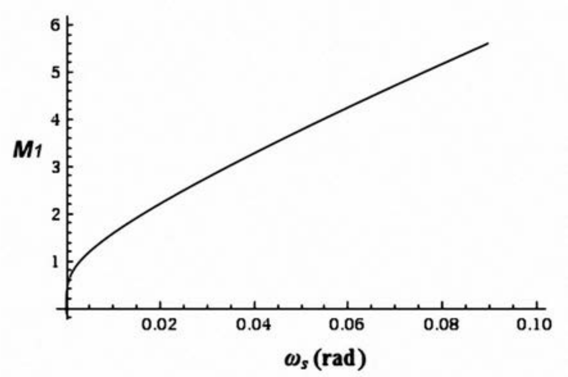

Fig.2. The variation of index sensation M_1 with respect to the solid angle subtended by luminaire No.1 in Guth's experiment, based on Eq.8

$$L_{sOLD} A_{OLD} = L_{sNEW} A_{NEW}. \tag{9}$$

Substituting ω_s with A in the Eq. 9, it will be converted to:

$$L_{sNEW} = L_{sOLD} \frac{\omega_{s\ OLD}}{\omega_{s\ NEW}} \tag{10}$$

In our proposed method, in order to modify the old sensation index M_{iOLD} and getting a new value M_{iNEW} where $M_{iNEW} < M_{iOLD}$, in which i indicates the ith luminaire, the Eq. 8 is rewritten as follows Eq. 11, which can be seen below.

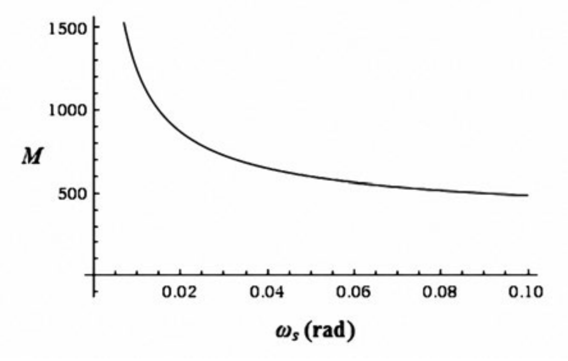

Fig. 3. The variation of new index sensation $M_{i\ NEW}$ with respect to the new solid angle subtended by each luminaire after modification

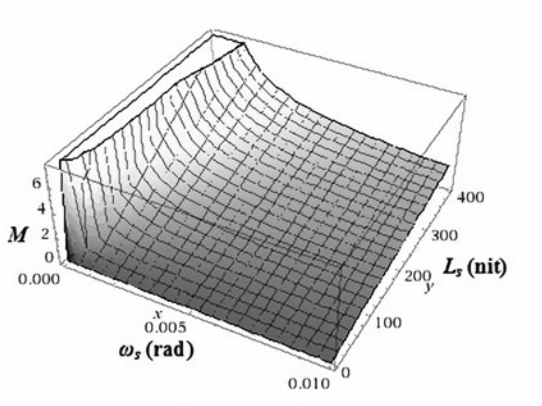

Fig.4. Index sensation (z) variation against the luminance (y) and the solid angle (x) subtended by each luminaire

By putting Eq.10 into Eq.11 it yields to Eq. 12 presented below.

Taking into consideration the new calculations, plotting $M_{i\ NEW}$ versus $\omega_{si\ NEW}$, again for luminaire No.1 in Guth's experiment, leads to a descending function for M when $\omega_{si\ NEW} > 0$ as depicted in Fig. 3.

Due to high values of L_s as compared to other factors in Eq.1, L_s value has a great impact on the M amount. Therefore, considering both variables of M i.e. L_s and ω_s, a three dimensional diagram can be plotted for M against ω_s and L_s as shown in Fig.4.

As it is clearly seen in Fig. 4, M increases with L_S growing and ω_S (or A) decline.

2.1. THE FORMULA FOR CALCULATING NEW *DGR*

If Eq. 12 is applied for all luminaires, then the sum of obtained M_{iNEW} can be replaced in Eq. 7 and the new DGR will become:

$$DGR_{NEW} = \\ = (M_{total\,OLD} - \sum_{i=1}^{n} M_{i\ OLD} + \sum_{i=1}^{n} M_{i\ NEW})^{N^{-0.0914}}, \quad (13)$$

where:

$M_{total\ OLD}$ = the total sensation index of luminaires in the FOV before modification,

N = the number of luminaires in the FOV,

n = the number of luminaires whose surface areas were modified.

Once the DGR_{NEW} has been calculated, the VCP_{NEW} can be determined either by using a conversion chart or a mathematical relationship. In the present study the lighting measurements conducted by IESNA handbook [1966–2000] have been employed thanks to the evaluation of sensation index M by several computational procedures and its description in detail step by step.

3. RESULTS AND DISCUSSION

Guth (1966) proposed a *VCP* computing model which has been the reference for all editions of IESNA handbook[5, 22]. In the present study, the Guth's model was used to obtain the lighting data. The lighting layout determined by Guth was symmetrical with respect to the line of sight and includes 64 luminaires 54 of which are in the FOV[22]. Our modification for *DGR* has been started with selecting luminaires whose index sensa-

$$M_{i\,NEW} = \frac{L_{s\,NEW}\,(20.4\,\omega_{s_{i\,NEW}} + 1.52\,\omega_{s_{i\,NEW}}^{0.2} - 0.075)}{P\{\frac{1}{5}\times[L_w\omega_w + L_f\,\omega_f + L_c\,(\omega_c - (\omega_{s_{i\,NEW}} + \sum_{i=1}^{N-1}\omega_{s_i})) + (L_s\omega_{s_{i\,NEW}} + \sum_{i=1}^{N-1} L_{s_i}\,\omega_{s_i})]\}^{0.44}}. \quad (11)$$

$$M_{i\,NEW} = \frac{L_{si_{\,OLD}}\;\omega_{si\,OLD}\,(20.4\,\omega_{s_{i\,NEW}} + 1.52\,\omega_{s_{i\,NEW}}^{0.2} - 0.075)}{P\,\omega_{si_{\,NEW}}\,\{\frac{1}{5}\times[L_w\omega_w + L_f\,\omega_f + L_c\,(\omega_c - (\omega_{s_{i\,NEW}} + \sum_{i=1}^{N-1}\omega_{s_i})) + (L_s\omega_{s_{i\,NEW}} + \sum_{i=1}^{N-1} L_{s_i}\,\omega_{s_i})]\}^{0.44}}. \quad (12)$$

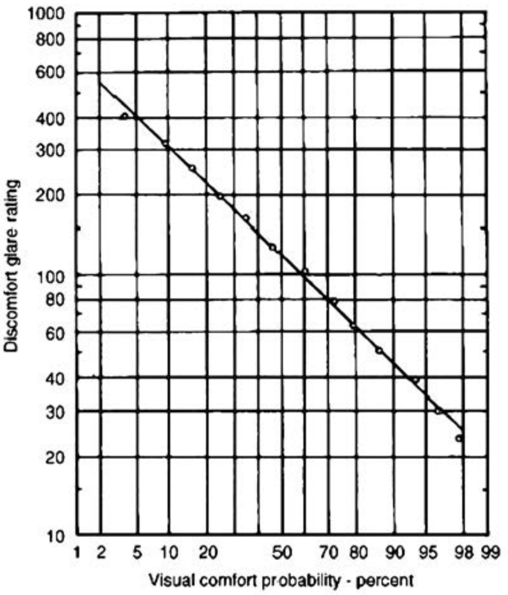

Fig. 5. The conversion chart to obtain *VCP* having *DGR*

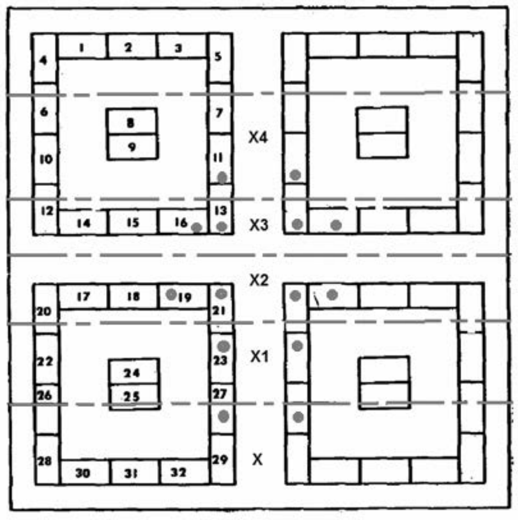

Fig. 6. The lighting layout with 54 luminaires in an interior lighting system: the fourteen modified luminaires, marked with circles and the x, x1, x2, x3 and x4 are positions of four observers, with courtesy of IESNA [1966]

tions M are higher comparing to the average of $\overline{M}$ among 54 luminaires and then reducing the values of the sensation index of these selected luminaires by 20 % as M_{NEW} = 80 %M_{OLD}. Table 1 shows the selected luminaires with their overall main characteristics. It is obvious from Table 1 that seven luminaires have the sensation index values greater than $\overline{M}$. The new subtended solid angles, ω_{siNEW}, were calculated for these seven selected luminaires by putting M_{NEW} values in the Eq.12.

The lighting data, L_s, P, and L_ω, were replaced in the equation represented in Table 1 and then ω_{siNEW} amounts were obtained. It should be noted that the terms $\sum_{i=1}^{N-1}\omega_s$ and $\sum_{i=1}^{N-1}L_s\omega_s$ in all equations in Table 1 are the summations of ω_s and $L_s\omega_s$ for all luminaires in the interior lighting system, except for luminaire i^{th} with the subtended solid angle ω_{siNEW}. Having ω_{siNEW}, the new luminaire surface areas, $A_{i\,NEW}$ can be calculated as below [5, 24]:

$$A_{i\,NEW} = \frac{\omega_{si\,NEW}}{(V/D^3)}, \tag{14}$$

where:

V and D are shown in Fig.1.

The corresponding results are shown in Table 2. It is seen from the Table 2 that the increase of luminaire surface areas is not proportional to their distances from observer (D) resulting from the simultaneous reduction of M amounts to ca. 50 % of the initial values.

3.1. CALCULATION OF NEW *DGR*

Once $\sum_{j=1}^{7}M_{OLD}$ and $\sum_{j=1}^{7}M_{NEW}$ for seven luminaires in Table 2 were calculated, the total M_{NEW} was determined as 289.4 and then the new DGR was obtained for 54 luminaires applying Eq. 13 as follows:

$$DGR_{NEW} = (382.8 - 186.8 + (186.8/2))^{54^{-0.0914}} = 49.18$$

Finally, VCP_{NEW} was obtained about 88 using the conversion chart, as depicted in Fig.5.

The main results for M_{total}, DGR and VCP before and after modification in the interior lighting system reported by Guth are shown in Table 3. The VCP improvement can be clearly seen from this table.

3.2 NEW DGR AND DIFFERENT OBSERVATION POINTS

The main objective of the present work was to develop a simple method to decrease DGR, and thereby improve VCP in a specific interior lighting installation by solely increasing surface area of

Table 1. The selected luminaires and the values of Eq. 12 parameters for each selected luminaire

N0.	L_{si} OLD	$M_{i\text{-}}$ OLD	M_{inew}	P	$\sum_{i=1}^{N-1}\omega_s$	$\sum_{i=1}^{N-1}L_s\omega_s$	ω_{siNEW} formula $L_{si\,OLD}\times\omega_{si\,OLD}(20.4\times\omega_{sNEW}+1.52\times\times\omega_{sNEW}^{0.2}-0.075)=M_{iNEW}\times\omega_{si\,NEW}\times\times P\times(A\times\omega_{sNEW}+B)^{0.44}$
1	158	7.3	3.65	1.95	0.378	130.71	$158\times0.0050(20.4\times\omega_{s1NEW}+1.52\times\times\omega_{s1NEW}^{0.2}-0.075)=7.11\times\omega_{s1NEW}(23.93\times\times\omega_{s1NEW}+62.36)^{0.44}$
2	178	7.8	3.9	1.69	0.385	130.98	$178\times0.00292(20.4\times\omega_{s2NEW}+1.52\times\times\omega_{s2NEW}^{0.2}-0.075)=6.59\times\omega_{s2NEW}(27.93\times\times\omega_{s2NEW}+62.41)^{0.44}$
3	168	8.0	4.0	2.72	0.376	129.47	$168\times0.0121(20.4\times\omega_{s3NEW}+1.52\times\times\omega_{s3NEW}^{0.2}-0.075)=10.88\times\omega_{s3NEW}\,23.93\times\times\omega_{s3NEW}+62.36)^{0.44}$
4	195	9.2	4.6	1.87	0.383	130.57	$195\times0.00479(20.4\times\omega_{s4NEW}+1.52\times\times\omega_{s4NEW}^{0.2}-0.075)=8.60\times\omega_{s4NEW}(23.93\times\times\omega_{s4NEW}+62.36)^{0.44}$
5	673	15.7	7.85	8.50	0.360	112.99	$673\times0.0275(20.4\times\omega_{s5NEW}+1.52\times\times\omega_{s5NEW}^{0.2}-0.075)=66.72\times\omega_{s5NEW}\,23.93\times\times\omega_{s5NEW}+62.36)^{0.44}$
6	326	18.0	9.0	2.81	0.370	125.80	$326\times0.0175(20.4\times\omega_{s6NEW}+1.52\times\times\omega_{s6NEW}^{0.2}-0.075)=25.29\times\omega_{s6NEW}\,23.93\times\times\omega_{s6NEW}+62.36)^{0.44}$
7	500	27.4	13.7	4.55	0.348	111.50	$500\times0.0400(20.4\times\omega_{s7NEW}+1.52\times\times\omega_{s7NEW}^{0.2}-0.075)=62.33\times\omega_{s7NEW}\,23.93\times\times\omega_{s7NEW}+62.36)^{0.44}$

some luminaires. In the cases where the ceiling can always be seen by the viewer in one direction, this simple method could be used appropriately to decrease *DGR* by only increasing the surface area of the luminaires having the most *M* among the others. In practice, it seems that the simplest way to reduce M_{total}, is to increase the surface area of luminaires installed on the ceiling without changing other properties of the lighting system like light intensity. In the present work, applying the mentioned modifications to the 14 selected luminaires, the total surface area increased by 57.64 ft^2 (an increase of 15 % for the whole luminaires) leading to the decline of M_{total} by 24 %. Subsequently, the *DGR* decreased by 19.3 % and then *VCP* improved by 8.6 %. These findings are true for an observation point which covers the 84 % of luminaires ((54/64)×100=84 %). However, such a reduction in *DGR* for observation points that cover less than 84 % of luminaires will be obtained by changing the surface area of fewer luminaires and inversely for observation points that cover more than 84 % of luminaires will be achieved by bringing more luminaires into account.

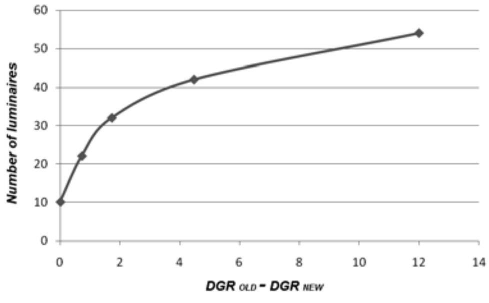

Fig. 7. Plot of $\Delta = DGR_{OLD} - DGR_{NEW}$ versus the numbers of luminaires in the observer's FOV, based on Fig.6

Considering X, X1, X2, X3 and X4 as different observation points as depicted in Fig.6, all of the determinant factors before and after modifying the luminaires surface area including M_{OLD}, DGR_{OLD} and VCP_{OLD} and also M_{NEW}, DGR_{NEW} and VCP_{NEW} were calculated for each observation point. The results are shown in Table 4. It should be noted that it was

Table 2. Calculated luminaire surface area for selected luminaires before and after modification

i	ω_{iOLD}	ω_{iNEW}	V/D^3	A_{iOLD}	A_{iNEW}
1	0.000500	0.00710	0.000567	7.50	12.52
2	0.000222	0.00411	0.000387	7.50	10.62
3	0.012100	0.01880	0.001610	7.50	11.67
4	0.004790	0.00690	0.000639	7.50	10.80
5	0.027500	0.04760	0.009770	2.81	4.87
6	0.017500	0.02850	0.002380	7.50	11.97
7	0.040000	0.07560	0.005330	7.50	14.18

Table 3. Comparison of M_{total}, *DGR* and *VCP* values before and after modification in the interior lighting system

	OLD (before modification)	**NEW (after modification)**
M_{total}	382.8	289.4
DGR	62	50
VCP	81	88

Table 4. Variation of M_{total}, *DGR* and *VCP* values for the different positions of an observer

	Observation point	**Number of luminaires in the FOV(*N*)**	M_{total}	***DGR***	***VCP***
OLD (before modification)	X	54	382.8	62	81
	X1	42	266	52.68	87
	X2	32	185	44.72	91
	X3	22	120.2	36.82	94
	X4	10	**50.4**	**23.93**	100
NEW (after modification)	X	54	289.4	50	88
	X1	42	234.8	48.21	88.5
	X2	32	175.28	43	92
	X3	22	117	36.10	94.5
	X4	10	**50.4**	**23.93**	100

not require to modify any luminaire for X4, and as a result, the values before and after luminaire modifications are the same for that point.

According to the Table 4, the *DGR* values are less for observation points that cover fewer luminaires. These findings show that the more the presence of bright luminaires happens in the FOV (*N*), the more *DGR* occurs. The difference between DGR_{OLD} and DGR_{NEW} ($DGR_{OLD} – DGR_{NEW}$), which was denoted by Δ, indicated that for observation points x to x4, it varied proportionally with the number of luminaires in the FOV (*N*), as depicted in Fig.7.

These results show that if *DGR* is acceptable for an observer who observes all installed luminaires, then it will certainly be acceptable for other observers for whom fewer installed luminaires are present in the FOV. It should be noted that for the interior lighting luminaires, which have already been installed, it is difficult to decrease *DGR* via increasing of the surface area of each luminaires, because *DGR* is reliant on *M* which in turn is not only dependent on luminance of each luminaire but also on viewer's position in a complex form. However, for interior lighting designs which are pre-installed, it is generally feasible.

REFERENCES

1. J.A. Veitch, G.R. Newsham, Determinants of lighting quality I: State of the science, Journal of the Illuminating Engineering Society, 1998, 27, pp. 92–106.

2. W.K. Osterhaus, I.L. Bailey, Large area glare sources and their effect on visual discomfort and visual performance at computer workstations, in: Industry Applications Society Annual Meeting, 1992., Conference Record of the 1992 IEEE, IEEE, 1992, pp. 1825–1829.

3. K. Van Den Wymelenberg, M. Inanici, Evaluating a New Suite of Luminance-Based Design Metrics for Predicting Human Visual Comfort in Offices with Daylight, LEUKOS,2015, pp.1–26.

4. J. Wienold, J. Christoffersen, Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras, Energy and buildings, 2006, 38, pp. 743–757.

5. IESNA, The IESNA lighting handbook: reference & application, 9th ed., 2000.

6. J.R. Benya, Controlling Glare, Deciphering this technical condition to create responsive Lighting Solutions, in: Architectural Lighting Magazine, 2010.

7. M.L. Eble-Hankins, C.E. Waters, VCP and UGR glare evaluation systems: a look back and a way forward, Leukos, 2005, #1, pp.7–38.

8. S. Carlucci, F. Causone, F. De Rosa, L. Pagliano, A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design, Renewable and sustainable energy reviews, 2015, 47, pp. 1016–1033.

9. R.G. Mistrick, A.-S. Choi, A comparison of the visual comfort probability and unified glare rating systems, Journal of the Illuminating Engineering Society, 1999, #28, pp. 94–101.

10. K. Van Den Wymelenberg, M. Inanici, A critical investigation of common lighting design metrics for predicting human visual comfort in offices with daylight, Leukos, 2014, #10, pp. 145–164.

11. W. Osterhaus, J. Veitch, Workshop on discomfort glare: Final report, in: 27th Session of the International Commission on Illumination, 2011.

12. W.K. Osterhaus, Office lighting: a review of 80 years of standards and recommendations, in: CONFERENCE RECORD-IEEE INDUSTRY APPLICATIONS SOCIETY ANNUAL MEETING, IEEE INC, 1993, pp. 2365–2365.

13. P.R. Boyce, C.M. Hunter, C. Inclan, Overhead glare and visual discomfort, Journal of the Illuminating Engineering Society, 2003, # 32, pp. 73–88.

14. C. Marty, M. Fontoynont, J. Christoffersen, M.-C. Dubois, J. Wienold, W. Osterhaus, E. Carco, R.F. Carco, User assessement of visual comfort: review of existing methods, in, Technical report, Ingelux, Lyon, 2003.

15. W. Kim, J.T. Kim, A formula of the position index of a glare source in the visual field, in: 3rd International symposium on Sustainable Healthy Buildings, SHB2010, Seoul, Korea, 2010.

16. R.E. Levin, Position index in VCP calculations, Journal of the Illuminating Engineering Society, 1975, #4, pp. 99–105.

17. T. McGowan, S.K. Guth, Extending and applying the IES visual comfort rating procedure, Illuminating Engineering, 1969, 64, 253p.

18. M. Luckiesh, S.K. Guth, Brightness in visual field at borderline between comfort and discomfort (BCD), Illuminating Engineering, 1949, 44, pp. 650–670.

19. S.K. Guth, A method for the evaluation of discomfort glare, Illuminating Engineering, 1963, 58, pp. 351–364.

20. R.E. Levin, An evaluation of VCP calculations, Journal of the Illuminating Engineering Society, 1973, 2, pp. 355–361.

21. G.A. Fry, A simplified formula for discomfort glare, Journal of the Illuminating Engineering Society, 1976, 6, pp. 10–20.

22. S.K. Guth, Computing visual comfort ratings for a specific interior lighting installation, Illuminating Engineering, 1966, 61, 634p.

23. L.B. Ford, D. Ranieri, Glare evaluation calculations applied to visual display terminals, Journal of the Illuminating Engineering Society, 1990,19, pp. 3–20.

24. I. Lewin, The Determination of Luminaire Projected Area, Journal of the Illuminating Engineering Society, 1973, 2 pp. 418–421.

Madjidi Faramarz

has a B.S. degree in applied physics from National university of Iran, M.Sc. in both physics and occupational health engineering from Tehran university, and Ph.D. in environmental engineering. He is a lecturer at the school of health, Zanjan University of Medical Sciences, where he has given many presentations and lectures mostly focusing on subjects like indoor lighting system measurement and design. His other main interested field of research is mathematical procedures to provide an appropriate model for measuring non-ionizing radiation based on the hot sources temperature in the working environments

Abedi Kamal ad-Din,

Ph.D. in field occupational health engineering, graduated from Hamedan University of medical sciences, faculty of health in 2014. He has more than 7 years experience in education and research in the field harmful physical and chemical agents of workplace. He is now holding the position of Assistant Professor in Kurdistan University of medical sciences, faculty of health, lecturing radiation health and protection, and lighting engineering design. He is a member of Environmental health research centre at Kurdistan University of medical sciences