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Evaluations of Low ambient task - surround lighting system in a simulated environment

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Abstract

Task -Ambient lighting provides energy saving but space surrounding the users can be dim and unpleasant. This study proposed a solution of an additional Surround Layer of light. Though a series of simulated lighting scenarios, it examined illumination requirements, dimensionality and appearance of the space by the use of Vector/Scalar and Task/Vertical Illumination Ratios. They were evaluated under several illuminance requirements, Task-Surround combinations and Surround Light source sizes. The results showed that by adding a Surround Light Layer, visual appearance of space surrounding the users could be enhanced and energy savings could be achieved.

Keywords: Lighting application, Task lighting, Task-ambient lighting, Task-surround -ambient lighting

Background

With ever increasing energy costs and the push to reduce energy consumption, there is constant pressure to reduce the amount of energy devoted to lighting. Energy savings can be achieved by simply turning down the amount of ambient lighting in the room, and supplementing light on work surfaces, such as table tops and desk tops, and in work spaces with task lighting. Because task lights do not need to generate the amount of light needed to illuminate an entire room, they consume less energy for the same task illumination level [1, 2]. From an energy efficiency point of view, only task lights would be used in a space, without ambient lighting. However, from a practical point of view, some ambient lighting is required for circulation and safety and to provide visibility to surrounding architectural structure and amenities in the space. For example, if the ambient lighting in a task lit space were reduced from 400 lux to 100 lux, the energy savings would be appreciable. As a result, task-ambient lighting becomes more prevalent in many lighting applications.

The problem with relying on a low level of ambient lighting is that the space immediately surrounding the occupants of the space will not be well lit. The task lighting will permit a person working at the task to see his or her task without difficulty, but colleagues sitting in proximity to that person will be in low light and shadows, making personal interactions more difficult. Similarly, the dimensionality of others objects within the space will be less appealing. A result, it makes the overall work environment dingy and less inviting. This study introduced a solution to this problem by an added layer of surround lighting that would provide good dimensionality and appearance within a well-lighted working spaces, namely Task-Surround-Ambient Lighting. As an example, Fig. 1a–c showed the appearance of the visual environments with Total Ambient Lighting, Task-Ambient Lighting and Task-Surround-Ambient Lighting.

Methods

The physical space

For this study, a computerized lighting environment was modelled. Figure 2 showed the geometry of the room model as well as the lighting layout. A room size of 32 ft × 32 ft with a ceiling height of 10 ft was established to represent the physical space. Reflectance of ceiling, wall and floor were assumed to be 80 %, 50 % and 20 % respectively.

A workstation comprised of 8 ft × 8 ft area and at a height of 5 ft partitions in the middle of the room was defined as the personal space where an individual would work and interact with others. A 4 ft diameter circular table was placed in the middle of this space with table top at 2.5 ft above the floor. The table top with a 50 % reflectance, was designated as the task surface.

The lighting layers

Small luminous diffusers with dimensions of 4in × 4in were chosen as the providers of illumination. A multitude of these diffusers would be used to provide three separate layers of lighting – Ambient Lighting Layer, Surround Lighting Layer as well as Task Lighting Layer. The luminous intensity level for each layers of diffusers could be adjusted separately to meet the illumination requirements. The intensity level for all diffusers within each lighting layer were the same. For Ambient Lighting Layer, there was a total of 225 of these diffusers mounted uniformly throughout the ceiling plane. The Surround Lighting Layer comprised of a 2 ft × 2 ft grid of 25 diffusers was located the middle the personal space at 3.5 ft above the desk-top. Similarly, for the Task Lighting Layer, 21 diffusers were mounted at 6 in. above the task surface.

It should be understood that the use of 4in × 4in luminous panels and the layouts of the panels were for clarity and simplicity in demonstrating the fundamental principle of this study and not as practical implementations. In specific, the panels on the ceiling plane could be regarded as having an equivalent lighting effect as that of general lighting luminaires such as 2 ft × 4 ft troffers or indirect lighting. The panels for task lighting layer was a representation of one or more task lighting luminaires capable of delivering even illumination across the entire task surface on the 4 ft diameter desktop. The choice of Task Lighting Layer at 6 in. above the work surface was to ensure that substantially all the light will reach the task surface. The study chose an array of panels

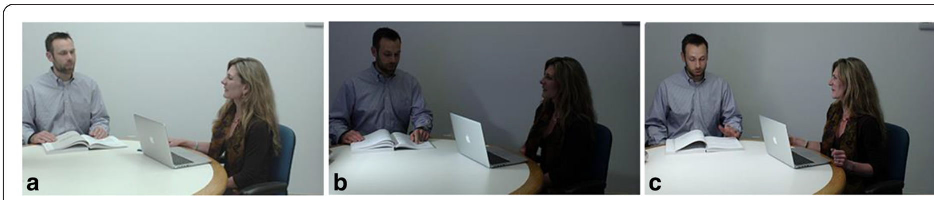

Fig. 1 a Visual appearance Ambient Lighting. **b** Visual appearance Task - Ambient Lighting. **c** Visual appearance Task - Surround - Ambient Lighting

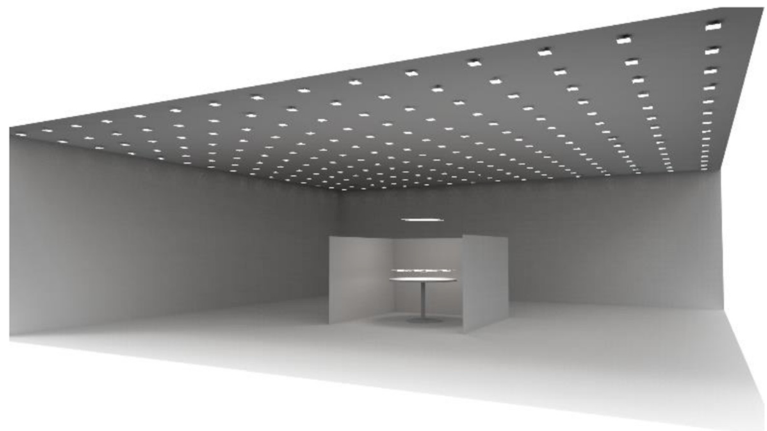

Fig. 2 The entire space

mounted at 3.5 ft height within the personal space to represent Surround Lighting layer because it was a simple way to distribute the light consistently over the entire volume of the personal space. Other layouts could be possible such as putting the surround light at a lower height and even on one side of the table for as long as the light could fill the entire volume of space. Finally, the luminous panels for surround light were considered as physical entities with 50 % reflectance while task lighting layer was treated as photometric entities only with no light blockage.

A minimum ambient illumination level of 100 lux for circulation and safety was assumed. Horizontal task surface illumination was set at 400 lux. Both of these values are within the recommendations from the Illuminating Engineering Society of North America [3].

Effects of different task surface illumination and size of surround lighting were also studied with the same physical model. All calculations were performed with Visual 2012 [4].

Referring to Table 1, four separate lighting categories and 6 lighting scenarios were designed for this environment:

1. Total Ambient Lighting (Scenario 1) – in this case, the workstation was provided with 400 lux of horizontal illumination from the ceiling mounted Ambient Lighting Layer only.

Table 1 Six lighting scenarios

Lighting category	Lighting scenario	Ambient lighting layer	Surround lighting layer	Task lighting layer
Total Ambient Lighting	1	400	0	0
Task-Ambient Lighting	2	100	0	300
Task-Surround-Ambient Lighting	3	100	100	200
	4	100	150	150
	5	100	200	100
Surround - Ambient Lighting	6	100	300	0

2. Task-Ambient Lighting (Scenario 2) – The workstation was lit with 100 lux from ceiling mounted Ambient Lighting Layer. Task Lighting Layer provided an additional 300 lux for a total of 400 lux of horizontal task surface illumination.
3. Task-Surround-Ambient Lighting (Scenario 3, 4 and 5) - 100 lux of illumination was provided by the Ambient Lighting Layer. The additional 300 lux was provided by three different combinations of Surround Lighting Layer and Task Lighting Layer. Table 1 showed the specific proportions of light from Surround lighting Layer and Task Lighting Layer. For example, in Scenario 5, 100 lux was provided by Ambient Lighting Layer, 200 lux by Surround Lighting Layer with the balance of 100 lux by the Task Lighting Layer.
4. Surround-Ambient Lighting (Scenario 6) - 100 lux of illumination was provided by the Ambient Lighting Layer. The additional 300 lux on the task surface was provided by Surround Lighting Layer only. Task Lighting Layer was not involved.

Lighting evaluation criteria

For this study, two location points were analyzed for each of the above lighting scenarios. Referring to Fig. 3, the side location point was a point 10 in. away from the edge of the table and 4 ft-2in from the floor. This represented a reasonable outer limit sitting distance at eye-level. Another location was a point at the center of the space at the same height from floor. These two points defined the volume of space surrounding the personal environment. Lighting evaluation criteria of the space were assessed by two factors:

1. The Contrast Ratio (CR) produced from the two location points facing towards the center of personal space for each of the 6 lighting scenarios. Contrast Ratio in this study was defined as the illumination ratio between the horizontal task surface illumination and vertical illumination looking straight forward at the evaluative point location. The criterion was that CR at these two location points be approximately 3:1 or below. This is an accepted metrics within a work space [4]. Referring to Fig. 3b, Vertical illumination was represented by E(x).
2. Vector/Scalar Illumination Ratio (V/S) [5, 6, 7] produced from the two location points facing forward from each of the 6 lighting scenarios. V/S is an index for appearance and dimensionality within a space. Table 2 showed the lighting effect at different Vector/Scalar Ratio. As per Table 2, V/S ratios in neighborhood of around 1 to around 2 would be considered acceptable for most general lighting purposes.

Computation of vector/scalar illumination ratio

Determination of vertical illumination and vector/scalar ratio at a point requires the calculations of cubic illumination [8] at that point. Cubic illumination specifies the spatial distribution of illumination in terms of illuminances on six surfaces of a small cube centered at that point (Fig. 3b).

Below is a summary on Vector/Scalar Ratio determination (after Cuttle [8]):

Let E(x) and E (−x) be the two opposing Illumination on the X axis

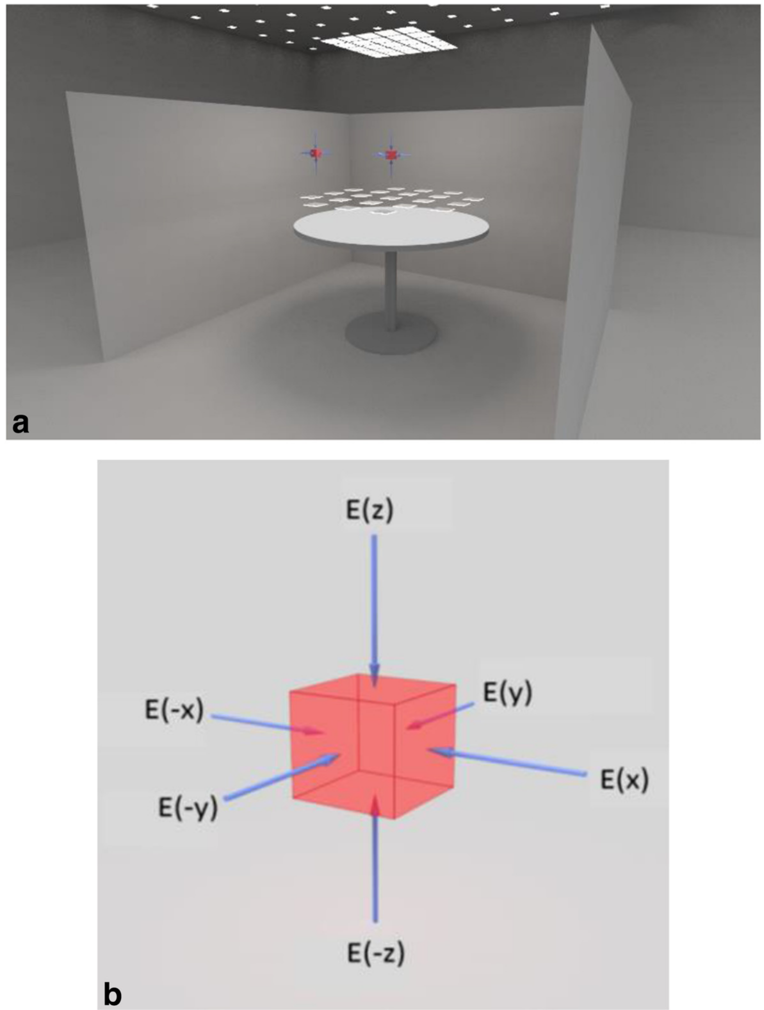

Fig. 3 a Surround lighting with 2 location points. **b** Cubic illumination at location point

E(y) and E (−y) be the two opposing Illumination on the Y axis
E (z) and E (−z) be the two opposing Illumination on the Z axis
Then, ʽE (x) = E(x) - E (−x) is the Illumination Vector on the X axis
ʽE(y) = E(y) - E (−y) is the Illumination Vector on the Y axis
ʽE(z) = E(z) - E(−z) is the Illumination Vector on the Z axis
The magnitude of the illumination Vector,

Table 2 Lighting effect at different vector/scalar ratio

Vector/Scalar ratio	Flow of light (Dimensionality)	Appearance
3.5	Dramatic	Theatrical
3.0	Very strong	Strong contrast, details not discernable
2.5	Strong	Suitable for display, too harsh for faces
2.0	Moderately strong	Pleasant for distant face
1.5	Moderately weak	Pleasant for near faces
1.0	Weak	Soft lighting for subdued effects
.5	Very weak	Flat, shadow free lighting

$$|E| = \sqrt{\left({}^{\prime}E(x)^2 + {}^{\prime}E(y)^2 + {}^{\prime}E(z)^2\right)} \quad (1)$$

The Scalar Illumination, Esr

$$Esr = |E|/4 + (\tilde{}E(x) + \tilde{}E(y) + \tilde{}E(z))/3 \quad (2)$$

Where ~ E(x) is the lesser of E (x) and E (−x)
~E(y) is the lesser of E(y) and E(−y)
~E (z) is the lesser of E (z) and E (−z)
From Equation (1) and (2), Vector/Scalar Ratio = |E|/ Esr

That is, V/S is the ratio of the magnitude of the illumination vectors to the average illumination arrived at that same point.

For this study, Vector/Scalar Ratios were computed for each of the two points.

It should be pointed out that both Factor 1 (CR < 3:1) and Factor 2 (1 > V/S > 2) requirements need to be met. That is, an acceptable Contrast Ratio has to couple with an acceptable Vector/Scalar Ratio to obtain a satisfactory lighting condition. As mentioned earlier, V/S in neighborhood of around 1 to around 2 would be acceptable. But within the acceptable range, a higher V/S should not be construed as better than that with a lower V/S ratio. Different lighting purposes and individual preferences would affect acceptability. However, for V/S that is much lower or higher than acceptable range would be considered as too flat or too harsh. Finally, the values of CR and V/S Ratios should be viewed as general guidelines and not to be interpreted with literal numeric exactness. Some degree of latitude in interpretation of the data are acceptable.

Results

Table 3 showed the computational results of all six lighting scenarios for two location points at task surface illumination level of 400 lux. It consisted of data for illumination on X, Y and Z axis, ʻE, ~E, magnitude of Vectors and Scalar Illumination, Contrast Ratios and Vector/Scalar Ratios for Task Surface Illumination of 400 Lux.

Table 4 was a condensed summary of Table 3 for easy reference.

Lighting result analysis

Referring to Table 4, values for vertical illumination were higher for side location point than the corresponding center location point. This was mainly due to the geometric relationship between the location points and the source of light - the ambient light, surround light and reflected light off the task surface. There were two factors to consider: first, the difference in distances from the light sources; second and the more importantly, the amount of light, E(+x) seen at the point locations. The first factor favored the center location point but the second favored the side location points. This was because center location point was in the middle of the table and only half of the light that was in front of the location point contributed to its vertical illumination. As can be seen from Table 3, all the values of Vertical Illumination and Contrast Ratios for center location points were less than that of the side location points. As a consequence, all CRs for side location points were less than that of the corresponding center location point.

Table 3 Detail data on computations of illumination, contrast ratio and vector/scalar ratios for task surface illumination of 400 Lux

	Center location point								Side location point							
Scenario 1	Ambient 400 Surround 0 Task 0															
	E (x)	227	E (−x)	220	'E(x)	7	~E(X)	220	E (x)	245	E (−x)	139	'E(x)	106	~E(x)	139
	E (y)	212	E (−y)	227	'Ey)	−15	~E(Y)	212	E (y)	196	E (−y)	207	'E(y)	−11	~E(y)	196
	E (z)	476	E (−z)	128	'E(z)	348	~E(Z)	128	E (z)	445	E (−z)	104	'E(z)	341	~E(z)	104
	Vector (Mag)	348	E (Vert)	227					Vector (Mag)	357	E (Vert)	245				
	Scalar	274	E(Horz)	400					Scalar	236	E(Horz)	400				
	V/S	0.12	CR	5.5					V/S	1.28	CR	4.88				
Scenario 2	Ambient 100 Surround 0 Task 300															
	E (x)	73	E (−x)	70	'E(x)	3	~E(X)	70	E (x)	82	E (−x)	39	'E(x)	43	~E(x)	39
	E (y)	70	E (−y)	71	'E(y)	−1	~E(Y)	70	E (y)	54	E (−y)	57	'E(y)	−3	~E(y)	54
	E (z)	120	E (−z)	110	'E(z)	10	~E(Z)	110	E (z)	113	E (−z)	41	'E(z)	72	~E(z)	41
	Vector (Mag)	10	E (Vert)	73					Vector (Mag)	84	E (Vert)	82				
	Scalar	86	E(Horz)	400					Scalar	66	E(Horz)	400				
	V/S	0.12	CR	5.5					V/S	1.28	CR	4.88				
Scenario 3	Ambient 100 Surround 100 Task 200															
	E (x)	118	E (−x)	112	'E (x)	6	~E(x)	112	E (x)	146	E (−x)	51	'E(x)	95	~E(x)	51
	E (y)	118	E (−y)	115	'E(y)	3	~E(y)	115	E (y)	70	E (−y)	73	'Ey)	−3	~E(y)	70
	E (z)	453	E (−z)	115	'E(z)	338	~E(z)	115	E (z)	163	E (−z)	49	'E(z)	114	~E(z)	49
	Vector (Mag)	338	E (Vert)	118					Vector (Mag)	148	E (Vert)	146				
	Scalar	199	E(Horz)	400					Scalar	94	E(Horz)	400				
	V/S	1.70	CR	3.39					V/S	1.58	CR	2.74				
Scenario 4	Ambient 100 Surround 150 Task 150															
	E (x)	142	E (−x)	132	'E(x)	10	~E(X)	132	E (x)	178	E (−x)	56	'E(x)	122	~E(x)	56

Table 3 Detail data on computations of illumination, contrast ratio and vector/scalar ratios for task surface illumination of 400 Lux *(Continued)*

	E (y)	143	E (−y)	137	'Ey)	6	~E(Y)	137	E (y)	75	E (−y)	78	'Ey)	−3	~E(y)	75
	E (z)	632	E (−z)	115	'E(z)	517	~E(Z)	115	E (z)	184	E (−z)	52	'E(z)	132	~E(z)	52
	Vector (Mag)	517	E (Vert)	142					Vector (Mag)	180	E (Vert)	178				
	Scalar	257	E(Horz)	400					Scalar	106	E(Horz)	400				
	V/S	2.01	CR	2.82					V/S	1.70	CR	2.25				
Scenario 5	Ambient 100 Surround 200 Task 100															
	E (x)	172	E (−x)	158	'E(x)	14	~E(X)	158	E (x)	219	E (−x)	62	'E(x)	157	~E(x)	62
	E (y)	174	E (−y)	165	'Ey)	9	~E(Y)	165	E (y)	83	E (−y)	86	'Ey)	−3	~E(y)	83
	E (z)	856	E (−z)	118	'E(z)	738	~E(Z)	118	E (z)	210	E (−z)	58	'E(z)	152	~E(z)	58
	Vector (Mag)	738	E (Vert)	172					Vector (Mag)	219	E (Vert)	219				
	Scalar	332	E(Horz)	400					Scalar	122	E(Horz)	400				
	V/S	2.23	CR	2.33					V/S	1.79	CR	1.83				
scenario 6	Ambient 100 Surround 300 Task 0															
	E (x)	228	E (−x)	206	'E(x)	22	~E(X)	206	E (x)	293	E (−x)	73	'E(x)	220	~E(x)	73
	E (y)	230	E (−y)	218	'Ey)	12	~E(Y)	218	E (y)	97	E (−y)	100	'Ey)	−3	~E(y)	97
	E (z)	1273	E (−z)	112	'E(z)	1161	~E(Z)	112	E (z)	258	E (−z)	68	'E(z)	190	~E(z)	68
	Vector (Mag)	1161	E (Vert)	228					Vector (Mag)	291	E (Vert)	293				
	Scalar	469	E(Horz)	400					Scalar	152	E(Horz)	400				
	V/S	2.48	CR	1.75					V/S	1.91	CR	1.37				

Table 4 Summary results of vertical illumination, contrast ratio and vector/ scalar ratios for task surface illumination of 400 Lux

Lighting scenario (Lux)	Vertical contrast ratio illumination (CR)				Vector/scalar ratio (V/S)	
	Center	Side	Center	Side	Center	Side
Ambient 400 Sur 0 Task 0	227	245	1.8:1	1.6:1	1.27	1.52
Ambient 100 Sur 0 Task 300	73	82	5.5:1	4.9:1	0.12	1.28
Ambient 100 Sur 100 Task 200	118	146	3.9:1	2.7:1	1.70	1.58
Ambient 100 Sur 150 Task 150	142	178	2.8:1	2.2:1	2.01	1.70
Ambient 100 Sur 200 Task 100	172	219	2.3:1	1.8:1	2.23	1.79
Ambient 100 Sur 300 Task 0	228	293	1.8:1	1.4:1	2.48	1.91

As for Vector/Scalar Ratios, in all cases, E(y) was small because the lighting was symmetrical on the + Y and-Y directions. For scenarios (3, 4, 5, & 6) involving surround lighting layer, at center location point, ʽE(x) was small because there was substantially equal amount of light from + X and -X direction. But ʽE(z) was large because light from surround lighting layer was larger than that of reflected light from desktop. Also, ʽE(z) increased as the proportion of surround lighting increased. For side location point, ʽE(x) was larger than that at center location point. This was due to higher illumination from + X direction for side location point. However, calculations showed that ʽE(z) for center point location was even larger than ʽE(x) for side location point. This resulted in higher Vector/Scalar Ratio for the center location points.

For scenario 1 with total ambient lighting, both location points "saw" approximately same size of ceiling above and therefore similar E(+z). This resulted in similar ʽE(z). As explained earlier, for center location point, E(+x) and E(−x) were similar, resulted in a smaller ʽE(x) than side location point. As a consequence, V/S ratio for center location point was smaller than side location point. For Scenario 2 with Task-Ambient and no surround light, ʽE(x) for center location point was small due to equal amount of light from + X and –X direction. This was not the case for side location point. Light from + X direction was more than that from the –X direction. As for ʽE(z), reflected light from desk top was much stronger for center location point than the side location point. This resulted in a higher V/S ratio at the side location point than at center location point.

Figure 4 was the comparison of Vertical Illumination and Vector/Scalar ratios between the two most practiced lighting scenarios – Total Ambient Lighting and

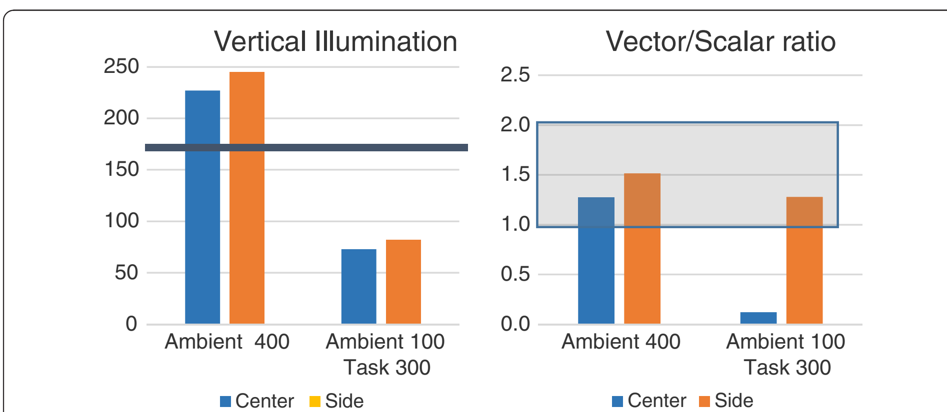

Fig. 4 Ambient vs Task - Ambient Lighting at 400 lux task surface illumination

Task- Ambient Lighting. The horizontal line on Vertical Illumination graph denoted Illumination Contrast Ratio (CR) of 3:1. Values above this line had less than 3:1 ratios and met the CR criterion. The shaded box on the Vector/Scalar Ratio Graph indicated the general area of acceptable V/S of between 1 and 2. As can be seen from Fig. 4, for both vertical illumination and V/S ratios, Total Ambient Lighting was superior to Task- Ambient lighting. Total Ambient Lighting of over 200 lux of vertical illumination was well within the 3:1 ratio. It rendered a brighter environment. It created a soft lighting effect with V/S of above 1 for both location points. This is typical of a general lighting system that normally found in an open office or a classroom. Task - Ambient lighting, on the other hand, appeared to be dingy and dark with a vertical illumination of below 100 lux and CR were well above 3:1. While the V/S for the side location point was acceptable, the low illumination and poor contrast ratio rendered the condition unsatisfactory.

Figure 5 introduced the Surround Lighting Layer. In this case, the lighting at task surface was not produced by task lighting at 6" above the task surface. Rather it was produced by Surround Lighting Layer located at 3.5 ft above the task surface. The surround lighting delivered light not only onto the task surface as required, but also delivered volumetric lighting to the entire volume of the personal space. The vertical illumination was high and well within the 3:1 contrast ratio. This resulted in brightening up of the entire personal space. It also drastically increased the dimensionality as indicated by the higher V/S for both location points. In fact, some individuals might find V/S ratio of 2.48 at Center Location Position as too high.

The above three lighting scenarios served as reference to the Task - Surround - Ambient Lighting to be described below. The Total Ambient Lighting (Scenario 1), the most prescribed type of lighting system, could be regarded as bench mark. The task - Ambient Lighting (Scenario 2) and Surround-Ambient Lighting (Scenario 6) anchored the two extremities of Task -Surround - Ambient Lighting. Under Task-Surround -Ambient Lighting (Scenario 3,4,5), the Ambient Lighting Layer would deliver low level illumination for circulation and safety for the entire 32′×32′ space. The Surround Lighting Layer and the Task Lighting Layer worked in concert to deliver the required task surface illumination on the 4′ diameter work surface as well as volumetric illumination within the immediate surroundings of the personal space.

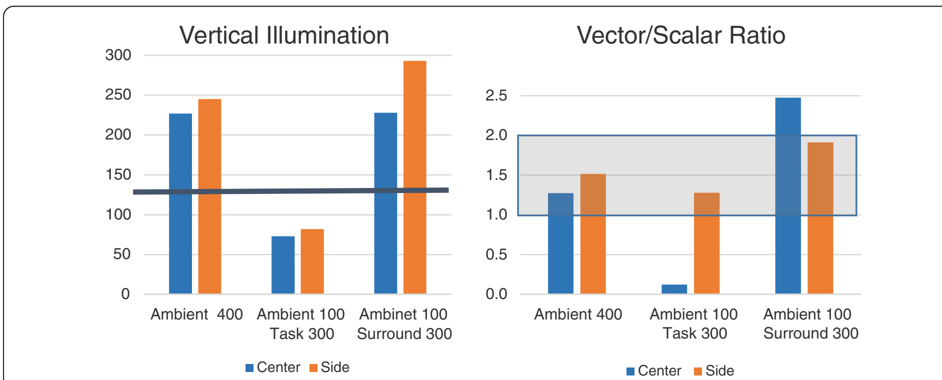

Fig. 5 Ambient vs Task-Ambient Vs Surround- ambient at 400 lux task surface illumination

Figure 6 showed the values of Vertical Illuminations and V/S Ratios for 5 different combinations of task and surround light levels from zero surround lighting contribution to total surround lighting contribution. The results showed that the higher was the surround light contribution, the higher was the vertical illumination. Satisfactory Contrast Ratios for all combinations achieved once the combination reached Ambient/ Surround/Task ratio of 100/100/200. (CR of 3.4 for 100/100/200 was slight beyond the criterion but as mentioned earlier, it should be viewed with certain latitude). V/S ratios moved higher as surround lighting contribution increases. Higher V/S ratio represents stronger dimensionality and appearance for the space. In this case, combinations of 100/100/200, 100/150/150 and 100/200/100 all were within the acceptable region with the possibly somewhat higher of the center location point for 100/200/100. As explained earlier, for scenarios involving Surround Lighting Layer, the side location points had higher vertical illuminations and lower V/S ratios as compared with center location points. The above deduction showed that for a wide range of proportionality between task and surround lighting layers, a user could achieve a satisfactory lighting condition based on the two factors CR and V/S Ratio. It should note that acceptable dimensionality and appearance of the personal space expressed in V/S ratio can be a personal preference. Hence, it would be possible that while one individual may find V/S Ratio of 2.2 as too high, another person may find it desirable.

The various combinations of task - surround light level pointed to an importance concept introduced by this study. That was to offer user the ability to adjust and dial-in to a specific combination of illumination from Task Lighting Layer and Surround Lighting Layer. This could be due to individual preference or specific lighting application. For example, with colleagues working together in the space, a higher ambient light level might be more preferred than when a single person working in solitude.

Effect of task surface illumination levels

Whether due to personal preference or desire for added energy saving, there are users who want to lower task surface illumination. Figures 7 and 8 showed the results of task surface illumination at 300 lux and 200 lux respectively. The general trends in terms of

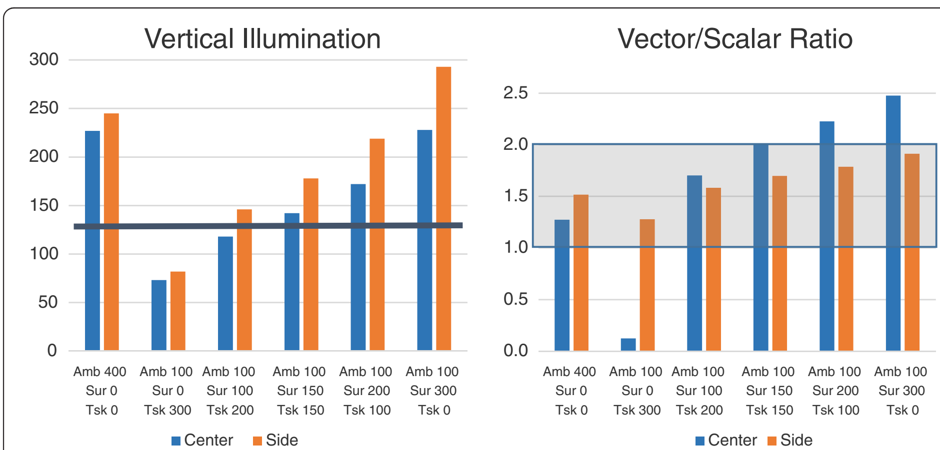

Fig. 6 Lighting comparisons with 2′ × 2′ surround lighting layer at 400 lux task surface illumination

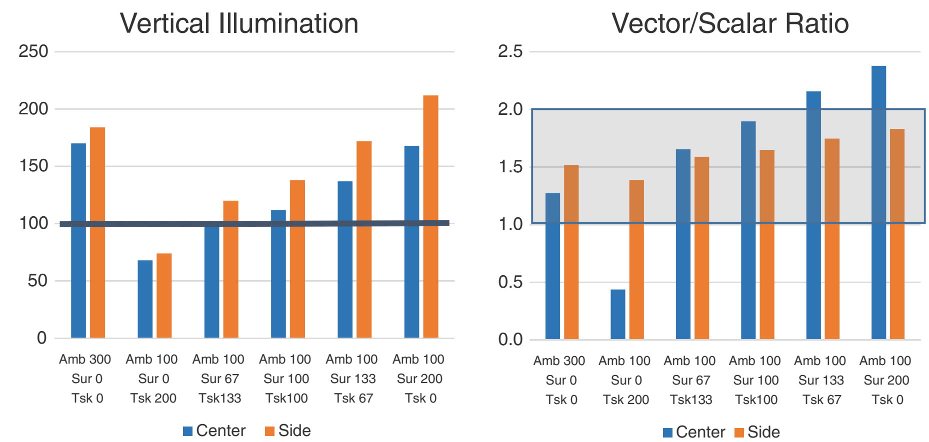

Fig. 7 Lighting comparisons with 2′ × 2′ surround lighting layer at 300 lux task surface illumination

CR and V/S were the same as that at 400 lux. That is, the higher was the surround lighting portion, the higher was the vertical illumination and V/S ratio. And for scenarios involving surround lighting layer, similar to 400 lux task surface illumination case, the side location points had higher vertical illumination and lower V/S ratio. When comparing across task surface illumination levels, the lower was task surface illumination, the more the values moved towards compliance. This was true for both CR and V/S. The reason was that at lower surface illumination level, Ambient Lighting Layer that was held to a constant value, contributed a larger proportion of the total task surface illumination. For example, comparing 100-150-150 (for 400 lux) vs 100-50-50(for 200 lux), the proportion of ambient light contribution moved from 25 % to 50 %. Hence, they were more compliant at the 200 lux level than of 300 lux and 400 lux level. All 3 combinations of Ambient /Surround/Task location points for three light levels were within the acceptable range both in terms of CR ratios and V/S ratios.

Effect of size

The above lighting analysis was done based on the Surround Lighting Layer size of 2 ft × 2 ft.

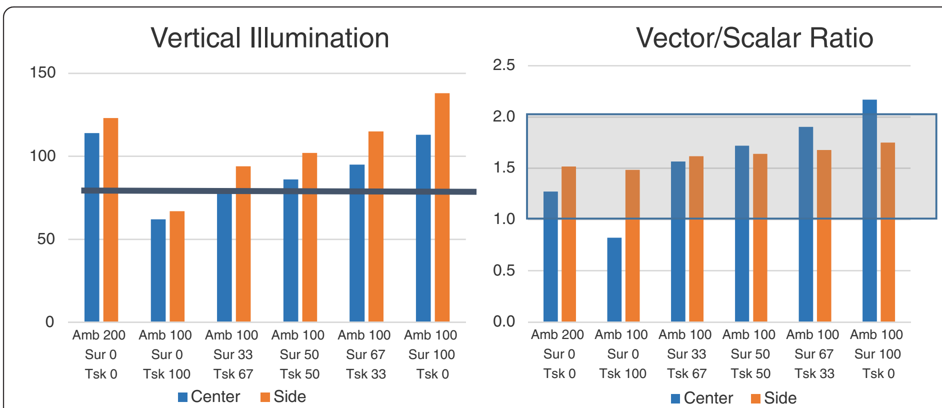

Fig. 8 Lighting comparisons with 2′×2′ surround lighting layer at 200 lux task surface illumination

It is realistic to expect that different spaces and the lighting designs will necessitate different sizes of Surround Lighting Layer. Figures 9 and 10 showed the results with Surround Lighting Layer at physical sizes of 1 ft × 1 ft, and 3 ft × 3 ft. The luminance of the panels was prorated to the number of panels employed such that the total light output from different size of Surround Lighting Layer were the same. As with 2 ft × 2 ft, Vertical Illumination and V/S ratios were calculated at both the center location points and side location points. The followings were observed:

1. For center point location, size difference affected vertical illumination. The larger was the size of surround light source, the greater was the vertical illumination. This was because when the surround light area is small, the light arrived at the vertical surface with a large incidence angle. It resulted in a small vertical illumination value. Conversely, for a larger surround light source, more light arrived at the vertical surface in smaller angle of incidence. It resulted in larger illumination values.
2. Size of ambient light affected the Vector/Scalar ratio at the center location points. The smaller was the area of the Surround Lighting layer, the higher was the V/S ratio. It was because as the size of the surround light decreases, high light intensity was focused in a small surround light size which produced a high illumination in the Z+ direction. That in turn resulted in high the illumination Vector ʿE(z). Another way to interpret this is that as the ambient light source gets smaller, greater luminance is needed for the surround light. This produced strong contrast and the lighting environment gets hash and dramatic, a situation which was not optimal for functional lighting. As the ambient source size increases, luminance intensity reduces and the environment gets softer and more comfortable.
3. Vertical Illumination did not affect the side location points appreciably. In this case, surround light source was farther away, the difference in incident angles among different source sizes were small. It resulted in less illumination value difference as indicated in Figs. 9 and 10. V/S ratio also were not affected by different surround light source sizes. This was a direct consequence of its further distance away from the surround light sources. That is, the illumination vector, ʿE(z) from Z+ direction,

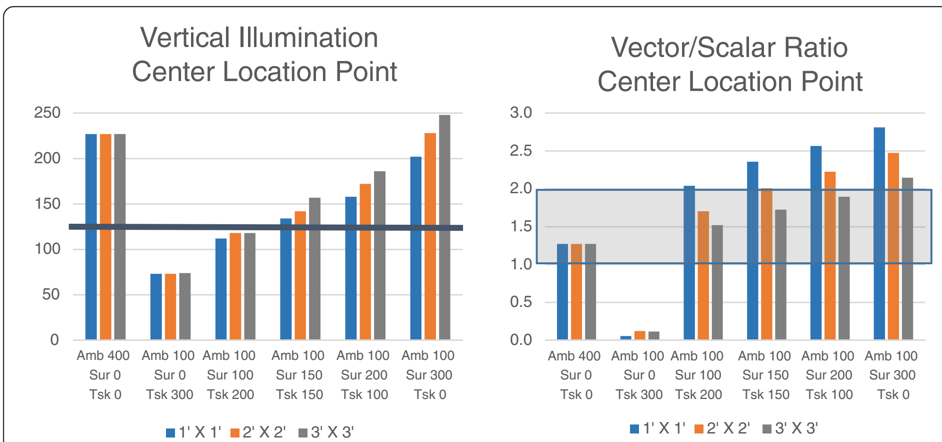

Fig. 9 Lighting comparisons of 400 lux task surface illumination with 1′ ×1′, 2′×2′ and 3′×3′ surround lighting layer center point location

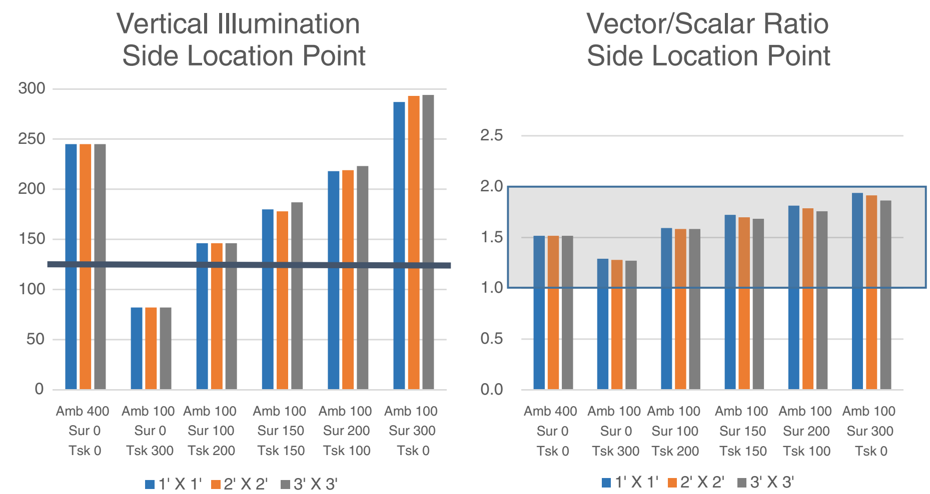

Fig. 10 Lighting comparisons of 400 lux task surface illumination with 1′×1′, 2′×2′, and 3′×3′ surround lighting layer side location point

for all three sizes were close to each other. Hence, the difference in Vector/Scalar were less.

4. For all location points, the larger the size of surround light the better was the CR and V/S Ratio with center location points more so than side location points.
5. Small surround light source created high V/S ratios especially for the center location point. High V/S ratio could result in lighting that is dramatic and even unnatural. This suggests small high intensity point sources would not be a good approach for surround lighting layer.
6. Smaller luminous size required higher luminance for equal light output. High luminance produce direct glare and reflected glare that can be detrimental to the visual quality of the overall space.
7. Results and assertions from task surface illumination of 400 lux can be extended to lower task surface illumination level. As mentioned earlier, when the overall task surface illumination was lowered, the proportion of ambient lighting layer contribution to task surface illumination increased. This would pull the results closer to that of the ambient only system. Hence, at lower task illumination, various sizes of Surround Lighting Layer would behave similarly as that of 400 lux and with more ease of compliance.

Energy consumption

One of the main motivations for Task - Ambient Lighting is to save energy. Figure 11 showed the three different layouts that were analyzed – 5 workstations, 9 workstations and 12 workstations. For the 12 workstation case, the layout might not be ideal, but it was only intended for energy consumption comparison. For each of the layout, 3 different task surface illumination were considered – 200 lux, 300 lux and 400 lux. Evaluations were performed with surround light size of 2 ft × 2 ft. Small sizes would increase lighting utilization marginally but effect will be minimal. Figure 12 showed relative energy consumptions for all six lighting scenarios. It took into account of energy

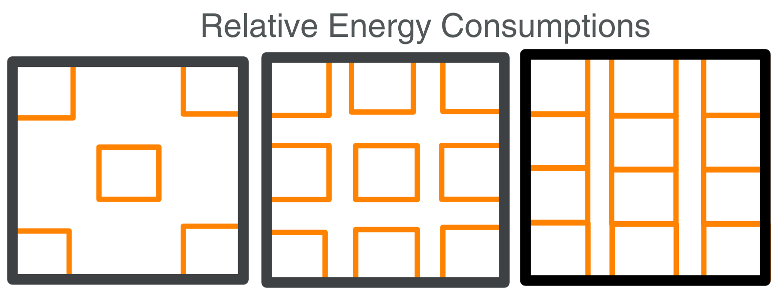

Fig. 11 Workstation layouts for 5, 9, and 12 workstations

consumption for the entire 32′ × 32′. It also differentiated areas of lower illumination for circulation and higher task surface illumination for personal space. The actual calculation procedure involved accounting for the relative intensity settings for the three layers of light and number of panels involved. Relative intensity settings were values necessary to obtain 400 lux, 300 lux and 200 lux respectively on the task surface for each of the 6 lighting scenarios. Furthermore, it was assumed that energy consumption of a light panel was linearly proportional to the luminance of the panel. The relative energy consumption for Total Ambient Lighting in each scenario was set to unity as reference.

The followings were observed:

1. As expected, Total Ambient Lighting had the highest energy consumption for all three workstation layouts and all lighting scenarios. Task - Ambient Lighting, on the other hand, consumed the least amount of energy.
2. The higher was the task surface illuminance, the higher was the relative energy savings. This was true for all lighting scenarios. This was because of a larger difference between task surface illumination and ambient illumination.
3. The lower was the density of workstations, the higher was the energy savings. The reason was that for fewer workstation layout, more area were assigned to circulation and safety that required lower illumination. Therefore the overall energy consumption was lower than that of a high number workstation layout.
4. Energy savings for Task-Surround-Ambient lighting system compared favorably with Task-Ambient system. This was especially true in case of high task surface illumination

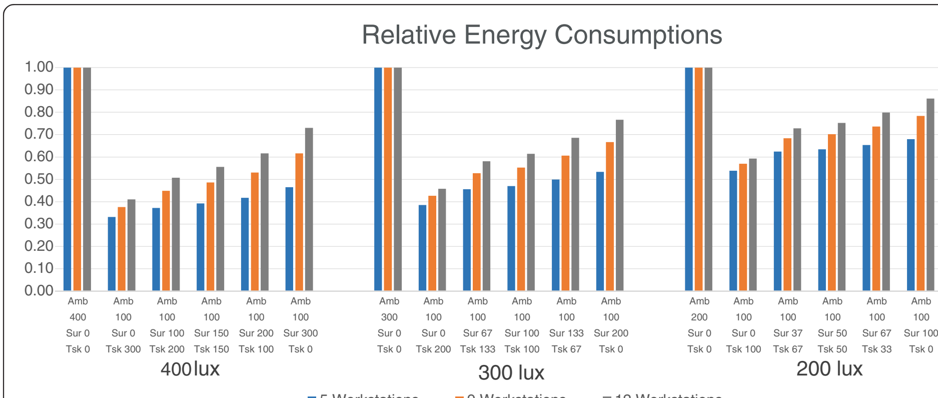

Fig. 12 Relative energy consumptions for 5, 9 and 12 workstations

and low density workstation layout. From data on Fig. 12, for 400 lux task surface illumination and 5 workstation, energy savings for Task-Ambient scenario vs Total Ambient Lighting scenario is about 63 %. Energy savings for 100 lux ambient, 300 lux surround and 0 lux task vs Total Ambient lighting is 54 %. So the difference in energy savings between the two extreme was only 9 %. As the proportion of surround light increased, the energy savings decreased.

Conclusions

This study introduced a lighting concept, namely the Task-Surround-Ambient Lighting system. It consisted of three lighting layers - the Ambient Lighting Layer, the Surround Lighting Layer and the Task Lighting Layer. The study employed two evaluative metrics - the illumination Contrast Ratio between task surface illumination and vertical illumination, and the Vector/Scalar Ratio. It showed that the addition of surround lighting layer was effective in enhancing dimensionality and the appearance of space over and beyond what Task-Ambient Lighting could offer. This was valid though a wide range of task surface illumination and surround light source sizes. The study also taught the idea of adjusting to different combinations of Task and Surround Lighting Layers which could allow the user to tune to for different lighting applications as well as personal preferences. Finally, this study showed energy savings for Task- Surround – Ambient Lighting compared favorably to that of Task-Ambient Lighting system.

Discussions

The study was anchored with two lighting measures. One was the illumination ratio between the task surface illumination and vertical illumination at the evaluative point location. The other was the Vector/Scalar Ratio at the evaluative location point. The first criterion is straight forward and generally accepted. As for the second criterion, there are a number of other models including, Cylindrical /Horizontal Illumination Ratio, Vector/Cylindrical Illumination Ratio and Target/Ambient illumination Ratio (TAIR) among others. Vector/Scalar Ratio is probably the most recognized metric. Hence this study adopted this criterion. While other metrics will yield different numeric results, but the essences and trends investigated by this study using Vector/Scalar should be similar.

This study was based on a specific set of lighting conditions in terms of physical room dimensions, reflectance, personal space locations and dimensions, evaluative point locations, photometric characteristics of the three layers of the luminaires chosen, as well as physical placement of the three layers of lights. It is reasonable to expect that different sets of input will not replicate identical numeric values. However, this should not alter the fundamental results and conclusions of this study. For example, we will not expect Task-Ambient lighting be superior to Task - Surround - Ambient lighting based on the evaluative metrics used in this study. The main trust of this paper is to gain insight of the interplay among the three layers of light. Hence, the study should be viewed in a conceptual perspective rather than quantitative precision. When a specific lighting layout is known, then the lighting can be evaluated for that specific condition.

The results of this paper is not limited to facial modeling. It is validity extend to appearance of any objects within the personal space. Hence Task - Surround concept is just as applicable with multiple persons interacting within the space, as with a single person working in solitude. It is important to point out that this study focused on the visual appearance surrounding the task area by means of Contrast Ratio and Vector/Scalar Ratio. Other important lighting quality factors such as task visibility, visual comfort, and health and wellbeing aspects though not the subjects of our study, should always be considered. Final, while the study was done with three discrete layers of lighting for clarity, in practice, it is conceivable that one luminaire through its light distributions and positioning, can function as more than one layer of light.

Endnotes

None

Competing interests

The author declare that he has no competing interest.

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