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A new direction for general lighting practice

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The currently accepted notion that the basic purpose of general lighting practice is to enable performance of visual tasks is examined and found to be lacking in substance. It is proposed that the purpose of lighting should be redefined in terms of the visual experience of illuminated surroundings, and two criteria are proposed for this purpose, both of which represent significant departures from conventional practice. The first assesses the adequacy of illumination for an activity in terms of the density of reflected light from surrounding room surfaces and the second is concerned with how the luminaire luminous flux is directed onto selected target surfaces. Taken together, these criteria offer a quite new approach for designing lighting installations for general practice.

1. A divided profession

The first illuminating engineering societies, formed in the early years of the last century, had no doubt that the purpose of illumination was to provide for visibility, later defined in terms of visual performance. Early schedules of recommended illuminance levels were set for efficient performance of typical visual tasks, but around the middle of the century, soon after the introduction of the fluorescent tube, those levels started to climb towards their current values, despite widespread application of technology over the same period to make visual tasks easier. Nonetheless, visibility continues to be quoted as the fundamental purpose of lighting. This is succinctly expressed in the Illuminating Engineering Society of North America's 'Guide to designing quality lighting for people and buildings' (2008), which opens with 'Task visibility is essential to lighting design; lighting exists to enable vision.'

This viewpoint deserves some examination. Figure 1 shows that, for a normal sighted 25-year-old subject, the typical reading task of black 12-point type on white paper requires just 20 lux to provide for the relative visual performance criterion of RVP = 0.98, this value being generally accepted as the highest practical RVP level for lighting applications. It can be seen that the font size would have to be reduced to 6-pt for the required illuminance to exceed 100 lux, or alternatively, reduced to 10-pt but printed onto dark-coloured paper, which has the double effect of reducing the background luminance and the task contrast. However, this value of 100 lux falls far short of the levels conventionally provided for applications where reading tasks are prevalent, which typically fall within the range 300 to 500 lux, and it is clear that such levels can be justified on the basis of visual performance only by presuming that either the users are partially visually defective or that they are persistently required to read very small print with very low contrast on low reflectance backgrounds. We are now surrounded by examples of recommended illuminance levels being far in excess of levels required to satisfy visual performance needs, while users are complaining of 'cave effect' and bland, gloomy workplaces.

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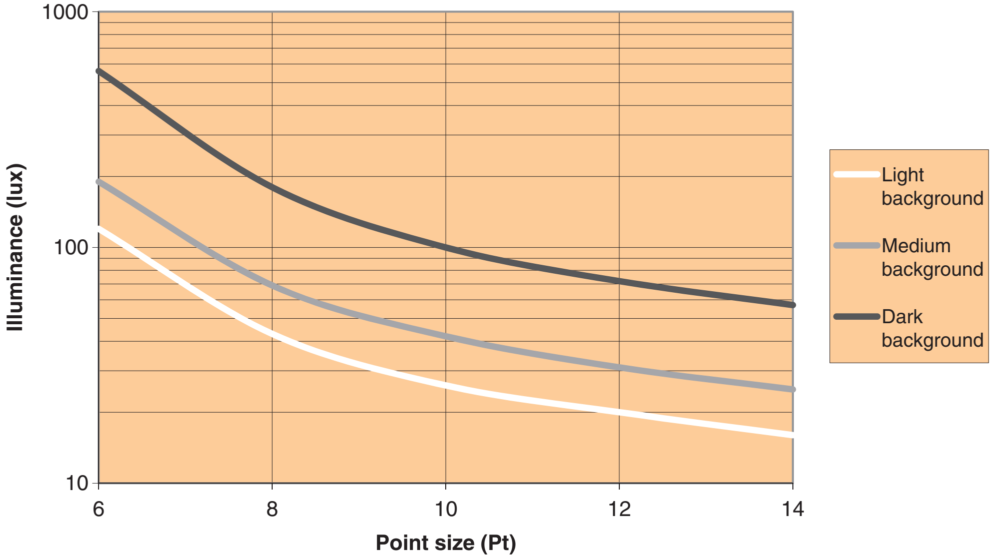

Figure 1. The task illuminance required to provide for relative visual performance RVP = 0.98 for a range of reading tasks. The reader is a normal-sighted 25-year-old with a viewing distance of 350 mm. The reading matter is black print, ranging from 6 - to 14-point size, on three types of paper: light (reflectance $\rho = 0.9$); medium ($\rho = 0.6$); and dark ($\rho = 0.3$).

Also around the middle of the last century, a new breed of lighting designer emerged. In the USA these were often stage lighting designers who had established close working relationships with some of the leading architects of the day and had brought the magic of the theatre into architecture. A rather different approach emerged in the UK that was largely attributable to one man: JM Waldram, originator of the Designed Appearance method.[1] While design philosophies may have differed, these lighting designers saw the purpose of lighting quite differently from the visibility approach: for them, it was a matter of how lighting may be applied to affect the appearance of surroundings, particularly of indoor spaces.

This difference of seeing the purpose of lighting being to provide for *visibility* or *appearance* continues to divide lighting professionals into two distinct camps that read different journals, attend different conferences, and join different professional groups. Worse, the division is widening. Lighting regulations made with the best of intentions – resources management, environment protection, and sustainability – follow the pattern set by the 'visibility' camp in that the provision of illumination is assessed in terms of illuminance values measured on 'visual task planes', which is almost invariably interpreted as referring to the horizontal work plane. A couple of examples will suffice to confirm the extent to which this concept pervades current thinking. The Society of Light and Lighting (SLL) Lighting Handbook (2009) states in relation to office lighting, 'Unless specified otherwise, the recommended maintained illuminance is measured on a horizontal working plane at desk height.' Again, the Handbook, and also the latest European workplace standard, EN 12464-1: 2011, prescribe a 'modelling index' defined as the ratio of mean cylindrical illuminance to the horizontal illuminance. It is obvious that the people who promulgate this index are unable to visualize a 'flow of light' other than vertically downwards, as produced by a uniform, overhead array of luminaires directing light onto the horizontal working plane. A lateral 'flow', as typically produced for highlighting an object of interest, or alternatively, as provided by side windows, gains no acceptance on this modelling index.

This preoccupation with the horizontal working plane means that the schedules intended to specify illumination adequacy have the effect of defining its distribution. As only lumens that are incident on the horizontal working plane count, demands for efficient lighting require that luminaires concentrate light onto that plane. Furthermore, although some standards state that their scope is restricted to workplaces, the lighting solutions that they advocate have become widely recognized as representing efficient lighting practice, so that they are applied much more broadly.

This situation is anathema to the 'appearance' camp, for whom the essence of lighting design is devising light distributions to suit individual locations and activities. They contrast brightness and dimness to influence the overall appearance of space and to produce local emphasis and modelling, which may come from any direction. Minimum work plane illuminance and uniformity requirements simply get in the way of what they are aiming to achieve, and in fact, they do not serve at all well the objectives of either camp. There is a real need for a totally new approach to prescribing the basis of lighting practice.

2. Two lighting design criteria for general practice

It is proposed that the basic purpose of lighting is redefined in terms of two lighting design criteria, both of which relate to the visual experience of lit surroundings, and both of which may be specified in photometric quantities that can be measured and calculated. While this paper deals with indoor spaces illuminated entirely by electric lighting, a future paper dealing with daylighting practice is envisaged.

The first of these criteria is perceived adequacy of illumination (PAI), which refers to the level of illumination that is likely to be judged just sufficient to make a space appear acceptably bright for the activity it houses. It is recognized that spaces where activity levels are high need to appear more brightly lit than those associated with more sedentary activities. The PAI level may be specified in terms of mean room surface exitance (MRSE), which is the measure of the overall density of reflected light within a space, measured in lm/m^2.

The second criterion is illumination hierarchy (IH), which involves devising distributions of illumination to express the visual significance of the activities or the contents of spaces. This may be achieved by controlling the distribution of illumination to express the function of a space or to give emphasis to selected objects. It is specified in terms of the target/ambient illuminance ratio (TAIR), which is the ratio of local illuminance incident on a target surface or object, to the pervading ambient illumination level indicated by the MRSE.

3. Mean room surface exitance

It has been shown[2,3] that:

$$MSRE = \frac{FRF}{A\alpha} \tag{1}$$

where FRF is first reflected flux, being the sum of products for each surface s of direct illuminance, area, and reflectance:

$$FRF = \sum E_{S(d)} \cdot A_S \cdot \rho_S \tag{2}$$

And $A\alpha$ is the room absorption, being the sum of products for each surface s of area and absorptance:

$$A\alpha = \sum A_S \cdot \alpha_S = \sum A_S \cdot (1 - \rho_S) \tag{3}$$

While it is quite straightforward to calculate MRSE from the above equations, measurement requires some thought. As MRSE is the average of flux densities exiting, or emerging from, all surfaces within the space, no single measurement can completely define its value. An approximate value can be obtained by taking up a position that brings most of the space into view, holding an illuminance meter vertically at eye level, and shielding it from direct light while taking a reading. Making comparative measurements in adjoining spaces with differences of light distribution and perceived levels of brightness can be an instructive exercise, but this procedure would not do for verification.

High dynamic range imaging (HDRi) has been proposed[4,5] for this purpose, and Figure 2 shows an HDR image produced from a series of differently exposed images from a tripod-mounted, calibrated digital camera fitted with a full-field lens. From the series of images, a computer program has generated a single image covering the full range of brightness, enabling every pixel to be recorded on a luminance-based scale. The light sources have been identified on-screen, and they are shown blanked out as they are

Figure 2. Full-field high dynamic range image (HDRi) for which each pixel is calibrated on a luminance-based scale. Light sources, both windows and luminaires, are shown blanked out as they will be disregarded for calculating mean room surface exitance (MRSE).

eliminated for calculating MRSE. It should not escape notice that as this procedure is based on distinguishing between direct and reflected light, it could be developed for also measuring discomfort glare in situ.

The objective for minimum lighting standards should be to ensure that the PAI criterion is satisfied irrespective of the illumination distribution, and it is on this basis that MRSE is proposed as the appropriate metric. More broadly, MRSE may be used as an indicator of how brightly or dimly lit a space appears to be, and Table 1 provides a guide to this aspect of appearance. An MRSE value of 100 lm/m^2 is shown as relating to an 'acceptably bright' appearance, but as has been explained,[2,3] these values have been derived from a range of reported research. More research will be needed to develop a range of values that corresponds to peoples' expectations for the appearance of different categories of indoor spaces, so that a specified MRSE value for a given category of indoor space should define the level below which people are likely to judge the space to appear dull, gloomy, and inadequately lit. As such, designers should treat it as a minimum level which they may exceed to achieve a greater sense of overall brightness, but should be cautious about going below.

4. Target/ambient illumination ratio

While the PAI criterion is concerned with adequate reflected flux (MRSE) within a space, the IH criterion is concerned with how the direct flux from the luminaires may be distributed to create a balanced pattern of illumination brightness that supports selected lighting design objectives, which may range from directing attention to the functional activities of the space to creating aesthetic or artistic effects. The designer selects target surfaces and designates values of TAIR, according to the level of perceived difference of illumination brightness to be achieved between room surfaces and between objects and the surroundings against which they are seen.

MRSE provides a useful measure of the ambient illumination level within a space, and except where there are obvious reasons to the contrary, it is reasonable to assume that the incident illumination on every surface will be the sum of direct illuminance and MRSE, so the total illuminance on a target surface:-

$$E_{tgt} = E_{tgt(d)} + MRSE \tag{4}$$

and the TAIR:-

$$TAIR = \frac{E_{tgt}}{MRSE} \tag{5}$$

This concept provides a basis for planning how direct light from the luminaires is to be distributed within the space. It follows that for any chosen target, the direct illuminance:

$$E_{tgt(d)} = MRSE(TAIR - 1) \tag{6}$$

Table 2 shows degrees of perceived difference, and this concept may be applied for making TAIR design decisions that concern the appearance of adjacent spaces, or of objects that are to receive selective illumination. The lighting designer designates TAIR values for selected surfaces or objects to signal

Table 1. Approximate guide to overall perceived brightness or dimness of illumination related to mean room surface exitance (MRSE)

Mean room surface exitance M_{rs} (lm/m^2)	Appearance of ambient illumination
10	Lowest level for reasonable colour discrimination
30	Dim appearance
100	Lowest level for 'acceptably bright' appearance
300	Bright appearance
1000	Distinctly bright appearance

Table 2. Approximate guide to perceived difference of illumination brightness related to mean room surface exitance (MRSE) difference or target/ambient illumination ratio (TAIR)

Perceived difference	Illuminance ratio
Noticeable	1.5:1
Distinct	3:1
Strong	10:1
Emphatic	40:1

noticeable, distinct, or strong perceived differences of brightness. The direct illuminance to be applied to each surface or object may be calculated from equation (6), and from these data, the distribution of direct luminous flux from the luminaires can be determined. The perceived difference concept (see Table 2) is based on an idea proposed by Lynes and Bedocs[6] that is quite different from that of the perceived brightness (Table 1), and I can say that I feel rather more confident about the reliability of the values shown. They are based on an experiment that involves subjects making assessments of perceived difference,[3] which I have conducted with student groups on numerous occasions and in widely different locations.

A designer may choose a large proportion of the room surfaces to comprise the target area, for example, when lighting a mural covering a whole wall, or an architectural icon, or a library reading area, or perhaps, the horizontal work plane of an industrial assembly shop (but it will happen by design, not by default!). Alternatively, the target area may be a small proportion, such as a solitary sculpture, or a featured retail display, or the preacher in his pulpit. Whichever, the designer who has decided upon the MRSE level can then decide upon the TAIR for each target area, and devise the lighting installation for a planned distribution of flux.

TAIR is not proposed as a suitable metric for lighting standards. Default conditions, such as illumination of the horizontal work plane, can be expected to persist and such conditions could be codified in terms of TAIR. However, the real role of TAIR is that of a tool which enables pursuit of selected lighting design objectives, which may range from very simple through to distinctly complex.

5. Design procedure based on MRSE and TAIR

The flowchart shown in Figure 3 and the spreadsheet shown in Table 3 should be referred to while following this procedure.

1) Consider a level of MRSE that would provide for an appearance of overall brightness or dimness appropriate for the location. Codes or standards specified in task plane illuminance are unlikely to be useful. Should there be a published MRSE value relevant to the location, it probably relates to the perceived adequacy criterion and so should be treated as a minimum value. Consider whether a higher level to give a brighter appearance would be appropriate, referring to Table 1 for guidance. The appearance of this space may be affected by adjacent areas. Consider whether it is to appear brighter or dimmer than those areas, and if so, by how much, this time referring to Table 2 for guidance. Where no minimum levels are specified, designing for an appearance of dimness becomes an option providing safety concerns are kept in mind.

2) Decide upon the design value of MRSE, this being the overall density of reflected flux to be provided within the volume of the space.

3) Estimate the area and reflectance value for each significant surface *s* within the room, making sure to include any surfaces or objects that you might decide to highlight

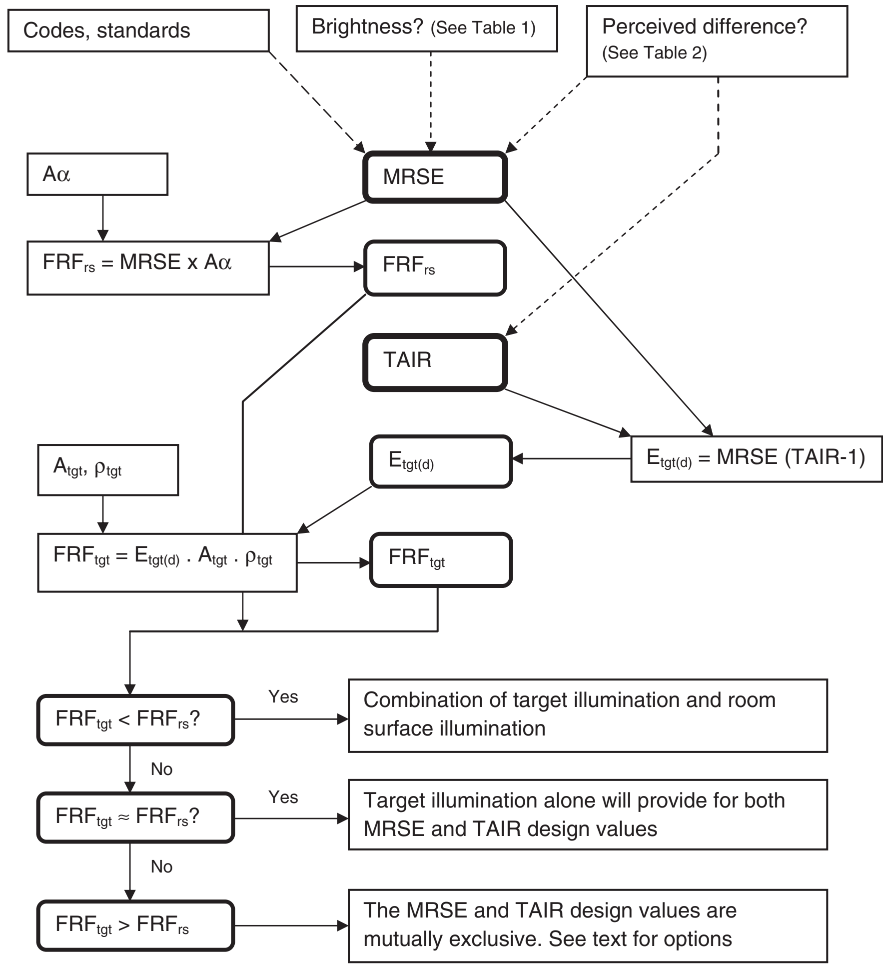

Figure 3. Flowchart for determining lighting options to provide for design targets specified in terms of mean room surface exitance (MRSE) and target/ambient illuminance ratio (TAIR) values.

with selective lighting. Calculate the room absorption for all room surfaces $A\alpha_{rs}$ using equation (3), and then, rearranging equation (1), calculate the first reflected flux reflected from room surfaces, $FRF_{rs} = MRSE \cdot A\alpha_{rs}$. These are the 'first bounce lumens' that initiate the interreflection process. Make a note of this value.

4) Consider the IH that the light distribution is to create in this space. Think about which objects or surface areas you want to highlight with selective lighting, and by how much. You will provide direct light onto these target surfaces, while surrounding areas will be lit mainly, or perhaps entirely, by reflected light.

5) Decide upon the design value of TAIR for each target area, taking account of how the appearance of the selected objects or surfaces will be affected by localized direct illumination. Table 2 may be referred to for guidance. Calculate the direct

Table 3 Spreadsheet for applying mean room surface exitance (MRSE) difference and target/ambient illumination ratio (TAIR) concepts in lighting design, showing the banking premises example described in the text. The user inputs the MRSE value, followed by the surface information in Columns 1–3, and the spreadsheet completes Column 4. The user then inputs *TSIR* values in column 5, and all of the remaining data are computed automatically from equations given in the text.

Project: Banking premises			MRSE (lm/m^2) 200			
Room surface	Surface area A_s (m^2)	Surface reflectance ρ_s	Surface absorption $A\alpha_s$ (m^2)	TAIR	Direct target surface illuminance $E_{ts(d)}$ (lx)	Target surface first reflected flux FRF_{ts} (lm)
Ceiling	113.3	0.75	28.3	1	0	0
Wall 1	19.8	0.65	6.9	1	0	0
Mural, wall 1	29.7	0.35	19.3	3	400	4158
Wall 2	40.3	0.65	14.1	1	0	0
Wall 3	24.8	0.65	8.7	1	0	0
Blinds, wall 3	24.8	0.8	4.9	1	0	0
Wall 4	28.2	0.65	9.9	1	0	0
Blinds, wall 4	12.1	0.8	2.4	1	0	0
Floor, public	5.1	0.25	38.2	1.5	100	1275
Floor, private	45.3	0.15	38.5	3	400	2718
Counter top	17.0	0.55	7.6	5	800	7480
Counter front	21.4	0.3	15.0	3	400	2568
Display panels	3.0	0.5	1.5	10	1800	2700
	Room surface absorption, $A\alpha_{rs}$ (m^2)		195.5	Target surface first reflected flux, FRF_{ts} (lm)		20 899
	Room surface first reflected flux, FRF_{rs} (lm)		39 096	FRF difference, $FRF_{rs} - FRF_{ts}$		18 197

illuminance $E_{ts(d)}$ to be applied to each individual target surface *ts* using equation (4).

6) Calculate first reflected flux from each target surface area A_{ts} and sum them, so that the total first reflected flux due to all target surfaces $FRF_{tgt} = \sum E_{ts(d)} \cdot A_{ts} \cdot \rho_{ts}$.

Then:

– If $FRF_{tgt} < FRF_{rs}$, then in addition to the light directed onto the target areas, the surrounding room surfaces will need some direct illumination to make up for the difference $FRF_{rs} - FRF_{tgt}$. This is needed to ensure that the MRSE design value will be achieved. The direct illumination onto the room surfaces does not need to be applied uniformly, and often the most effective way will be to spread light over large, high-reflectance surrounding surfaces such as ceiling and walls. Concentrating this light onto small areas may cause them to compete visually with the target areas. There is plenty of scope for ingenuity in devising ways of raising the overall illumination brightness without detracting from the selected targets.

– If $FRF_{tgt} \approx FRF_{rs}$, the target illumination alone will provide for the design values for both MRSE and TAIR. This is because reflected light from the target surfaces will both provide the design level of ambient illumination and achieve the intended balance of target/ambient levels. A serendipitous outcome.

– If $FRF_{tgt} > FRF_{rs}$, the design values of MRSE and TAIR cannot be achieved simultaneously in this situation. The reason is that if the direct target illuminance is applied, the reflected flux will raise MRSE above the design level and reduce TAIR below the design levels. Usually the most effective remedial action will be to reduce the total target area, such as by concentrating the objects to receive direct light into more restricted areas. Otherwise, it will be necessary to reduce either, or both, ρ_{tgt} and ρ_{rs}, but unfortunately, lighting designers seldom have much influence over reflectance values. A compromise may be inevitable, but at least the outcome will not come as an unpleasant surprise.

6. Example: a banking premises

For this example, Table 3 shows the output of a spreadsheet that is easy to set up and greatly facilitates the calculations. The designer has decided upon an MRSE level of 200 lm/m^2, and has input this value, and also the first three columns listing room surfaces and their properties. Column 4 gives the computed room absorption values, and at the bottom shows that 39 096 lumens of first reflected flux from the room surfaces is required to provide the MRSE level. Next the designer enters a TAIR value for every surface. This is the vital stage of the process, and Column 5 forms the statement of design intent for IH. The two remaining columns are completed automatically from these data, and show that 20 899 lm of the required FRF will be provided from the target surfaces, which means that the difference of 18 197 lm will need to be made up by reflected light from other room surfaces.

At this point, we can turn to familiar illumination engineering techniques for determining the luminaire layout. Various options for providing the deficit FRF may come to mind, but a simple and efficient solution would be uplighting. The direct average ceiling illuminance:

$$E_{clg(d)} = \frac{FRF_{clg}}{A_{clg} \cdot \rho_{clg}} = \frac{18197}{113.3 \times 0.75} = 214\,\text{lux} \qquad (7)$$

This direct illuminance added to the MRSE would give total ceiling illuminance E_{clg} of

414 lux, giving a TAIR value of just over two. Table 2 indicates that this would correspond to a perceived difference between noticeable and distinct, but this effect could be reduced to something less than noticeable by also applying some light onto the walls and so reducing $E_{clg(d)}$ and the TAIR value for the celling. Those two walls with the light-coloured blinds could get some wallwashing, which would work providing that the staff could be relied upon to pull down the blinds during darkness. It would be necessary to check about that, and after all, this is the way that lighting design happens, and it is part of the reason why no two designers would come up with identical schemes.

Moving on to the to the target surfaces, Column 6 lists the direct illuminance levels required. Familiar design software can be used, the trick being to set all reflectance values to zero so that the computed illuminance values given are direct illuminance. This works well for the larger surfaces, but for spotlighting individual three-dimensional objects I prefer to use the cubic illumination[7] concept which sums the illuminance contributions from multiple sources on the faces of a small cube. Table 4 shows a spreadsheet output in which each luminaire is located relative to the cube by dimensions on x, y, and z axes. The full version of this spreadsheet includes vector and scalar data, which are beyond the scope of this paper.

7. Discussion

The foregoing design procedure leads to a solution based upon satisfying predetermined design objectives for:

- Overall perceived brightness or dimness of illumination.
- Perceived difference of brightness of illumination between the design space and adjacent spaces.
- An IH, which involves creating a light distribution to give graded levels of perceived difference of illumination between selected room surfaces, or objects and their surroundings.

This leaves open the question, how well will this lighting enable people to perform visual tasks? What has happened to the notion of providing illumination to compensate for visual task difficulty? I am conscious that Mark Rea has recently commented[8] that my approach completely ignores task visibility, so let me set the record straight.

Table 4 Spreadsheet for direct illuminance calculations for multiple light sources based on the cubic illumination concept.[7] The cube is located at the intersection of x, y and z axes, and for each source the user inputs the luminous intensity in column 2, and locates the source relative to the cube by distances X or −X, Y, or −Y, and Z or −Z on the corresponding axes. The illuminance values on each face of the cube are computed by the spreadsheet, where $E_{(x)} = X(I/D^3)$.

Source	*I* (cd)	Distance on *x*, *y*, *z* axes (m)						*D* (m)	I/D^3	Cubic illuminance values (on cube surfaces)					
		X	−*X*	*Y*	−*Y*	*Z*	−*Z*			$E_{(x)}$	$E_{(-x)}$	$E_{(y)}$	$E_{(-y)}$	$E_{(z)}$	$E_{(-z)}$
S1	1000	2.2		3.7		1.6		4.59	10.32	22.7	0	38.2	0	16. 5	0
S2	1200	0	4.1	1.9		2.8		5.32	7.99	0	32.7	15.2	0	22.4	0
S3	800	3.2			2.7		0.8	4.26	10.32	33.1	0	0	27.9	0	8.3
S4	220	0	2.6	2.9			2.2	4.47	2.46	0	6.4	07.1	0	0	5.4
S5		1						1	0	0	0	0	0	0	0
S6		1						1	0	0	0	0	0	0	0
						Total cubic illuminance values (lx)				55.8	39.1	60.5	27.9	38.9	13.7

It is evident from Figure 1 that the illumination levels that are routinely provided in workplaces are sufficient to enable normal-sighted people to perform moderately demanding visual tasks with high levels of visual performance. I should add that any competent designer who applies the foregoing procedure in a workplace would take into account the distribution of work activities in allocating TAIR values. Furthermore, during the past half century we have seen many examples of technology eliminating difficult visual tasks or replacing them with new forms of display, but still, some activities remain that depend on fine visual discrimination. Examples occur in surgery and quality control inspection (both situations where it is usually impractical to alter the task), and where such visually-demanding activities occur, my argument is that the first concern of the lighting designer should be to provide a well-lit space in which workers are adapted to at least moderately high brightness levels with total absence of glare, of both discomfort and disability varieties. After that, attention should be given to devising spatial and spectral distributions of illumination to maximize the luminance contrast of the critical detail of each visually-demanding task. This requires illumination engineering skill, and often the solution will comprise some form of local lighting with a degree of operative control. While high illuminance may be part of the solution, the old notion that illuminance is applied to compensate for task difficulty is inappropriate. Visually-demanding tasks call for specific solutions that are separate from the means for providing well-lit environments. Such situations apart, however, we should acknowledge that we live in era when most of the things that we need to be able to see have been designed to be seen.

It needs to be recognized that while equation (1) is endearingly simple, it is imprecise. This is because it assumes that reflected flux is distributed evenly over all room surfaces, whereas each surface 'sees' only other surfaces. For the flux reflected from a large room surface, such as a ceiling, some error is inevitable and whether it is significant will depend on circumstance. It should not be expected that the PAI criterion, being an indicator of subjective response, will ever be specified with such precision that MRSE differences of a few percent will matter, but when a supplier is held to meeting a standard rather different judgments apply. We can expect that the prospect of MRSE-based standards would lead to rapid development of design software that would accurately model complex interreflection processes.

Switching from current procedures involves far more than a change of numbers. It will lead to a changed understanding of how light may be distributed within an interior space for visual effectiveness and energy efficiency. Consider, for example, a situation where you want to achieve a high value of TAIR: What should you do to maximize its value? For a start, choose your target object, and light it with minimum spill so that it is the only surface to receive direct light. Then the maximum value of task/ambient illuminance ratio:-

$$TAIR_{\max} = \frac{E_{tgt(d)} + MRSE}{MRSE} = \frac{A_{rs}(1-\rho_{rs}) + A_{tgt}\cdot\rho_{tgt}}{A_{tgt}\cdot\rho_{tgt}} = 1 + \frac{A\alpha_{rs}}{A\rho_{tgt}} \tag{8}$$

The first surprise is that the direct target illuminance $E_{tgt(d)}$ is not a factor, meaning that as you adjust the light level up and down, the target/ambient balance remains unchanged. The ratio value is simply proportional to the room absorption [equation (3)] and inversely proportional to the target reflection, this being the product of target area and reflectance. So the answer is to choose a small, low-reflectance object and display it in a large, low-reflectance space. If you replace the object with one of high reflectance, you will raise MRSE, but not $E_{tgt(d)}$, so that TAIR will reduce. Jay[9] has reported a similar study examining maximum attainable luminance contrast.

Another aspect that will present a fairly steep learning curve will be the increased emphasis upon room surface reflection properties. In particular:

- If the aim is to achieve room brightness with high energy efficiency, high room surface reflectance values are as important as lamp efficacy and luminaire efficiency, and of particular importance are the reflectance values of the surfaces which provide the first reflected flux. It will often be found that uplighting and wallwashing are more energy efficient than downlighting.

- If the aim is to achieve high TAIRs, then low room surface reflectance values are necessary, particularly if the target area comprises a substantial proportion of the total room surface area. The problem here is that the first reflected flux from the target may raise MRSE to a level that prevents even moderately high levels of TAIR from being achieved.

Some emphasis has been placed on the proposal that lighting standards should be specified in MRSE, as this is seen to be the catalyst for change. That there is a need for standards that specify illumination minima is abundantly evident, but what is less obvious is the extent to which the form in which this is currently specified sets a pattern of thinking that pervades general lighting practice. The ubiquitous workplane governs not just calculations and measurement procedure, but luminaire design, installation practice, as well as monitoring and the operation of lighting controls. All of this follows from standards that dictate one particular distribution of illumination. Conversely, MRSE specifies adequacy without restricting distribution, and TAIR empowers designers to provide balanced illumination distributions to suit individual spaces, their contents, and the human activities that they house. It is time for change.

8. Summary

A case has been made for the prime criterion for future indoor lighting standards to be PAI specified in terms of MRSE. This differs from current practice on three main counts.

- Illumination adequacy is specified in terms of density of reflected light, not incident light.

- The specified level is an ambient quantity, not related to a particular plane, position, or direction of view.

- The distribution of illumination within the space is not defined, and uniformity is not stated to be an objective.

The aims of this proposal are that:-

- Lighting designers may start from the shared understanding that the fundamental purpose of indoor lighting is to satisfy the PAI criterion.

- That all compliant indoor spaces covered by lighting standards based on PAI have a high probability of being assessed as adequately illuminated.

- Once the PAI criterion is satisfied, designers have freedom to prioritize their design objectives. This may be achieved by determining an IH specified in terms of TAIR values.

- The foregoing will be a step towards closing the division within the lighting profession that is discussed in the opening section of this paper.

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Comment 1:

I Macrae (President of the Society of Light and Lighting and Head of Global Lighting Applications Management, Thorn Lighting)

It is always with intrigue that I open a paper that develops the idea of lighting a space around metrics other than the widely accepted and much maligned illuminance of the working plane. Yet again Kit, as with many others, questions the way that we should light a working plane, and do it to perform a wide range of visual tasks across a multitude of media, times of day and human beings.

The proposals in Kit's paper deserve deep thought and respect, but I would vouch remain fundamentally flawed in the same way as workplane illuminance is.

Firstly, it is worth pointing out that a good lighting designer does not play to illuminance, or to a working plane, and more often than not will be thinking and perhaps even calculating the play of luminance across a range of surfaces. At the other end of the scale there is a group of 'lighters' who barely understand the concept of illuminance and work to minimum numbers as tick boxes of so called design. Herein lies the first problem with Mean Room Surface Exitance (MRSE) and other luminance-based design methods. They demand an understanding of lighting, the flow of light, contrast and reflectance beyond that which most practitioners of lighting design possess. Legislation and guidance has indeed made this type of designer more prevalent, some 80% of design is done to numbers by those with a basic understanding of light. But there have been some changes that this paper has overlooked, perhaps. A move away from workplane illuminance to task-based illuminance started many years ago. Agreed the move is slow, but now the task is not horizontal or based on a fictitious workplane, and there is no stipulation that illuminance is the only appropriate measure, it just happens to be the easiest for the building industry to work and to litigate with. Also, we see moves to recognise cylindrical illuminance, background and surround illuminance in addition to other numbers. Not ideal as Kit rightly points out, but a positive move nonetheless.

The building industry dominates building design and does so in order to deliver low cost and fast buildings for the most part, and that influences so much in the design process. Though a laudable approach, the use of design methods for lighting that demand rooms to be well defined with detailed surface finishes and furniture layouts, and indeed based around a known task and relatively fixed viewing position are dead before they start in most building design. Design for appearance works well when you can control task, location, view, and colour, but in most modern multitasking and constantly changing environments, the problems with a fixed lighting design is that it will need to change too. Until we have luminaires that offer complete flexibility in luminance and distribution, most clients are not going to change the lighting when the office is moved around.

This is my second problem with measures such as perceived adequacy of illumination and mean room surface exitance. Knowing the viewing position and task is often difficult, except in deliberately staged scenes. How does the MRSE method deal effectively with reading for instance? Assuming you know roughly where the paper will be held then it is possible to balance the brightness of the relevant surfaces to make the room feel adequate and the text on the page to still stand out, but for who and is that really paper? I ask who, because the eye of the beholder is important, specifically its age and condition, and I raise paper because I read Kit's proposal on an iPad, of course a self-lit task over which Kit's method has no control. Add to this that the chair I sit on is on wheels and allows me to rotate, move or recline and I would ask can a lighting designer really cater for all these changes and devise a hierarchy of illumination that works for myself, my task, my view, and the view of the other ten people in the office? Finally, I sit at a desk, uniformly lit, to a lighting level that does not suit me, but which suits my colleague sat next to me, suggesting a need for task, ambient and accent lighting, and the task lighting would change completely the MRSE received at the eyes of a number of people in the space.

Actually, I like MRSE as a concept, much in the way I like luminance-based design overall, it is just the fit to modern building design that makes it difficult to practice. Turning up on site to explain poor illuminance levels often results in discussions around the change of the wall colour to deep blue, or the furniture from pine to mahogany, actually its not the lighting measure that's always at fault. Agreed illuminance and luminance both suffer problems. Perhaps we should correct the design process first, then the lighting design methods?

This goes for target/ambient ratios too, unless you have a space that is really well-defined, in which case MRSE and TAIR make perfect sense.

There are many elements of Kit's proposal that loosely fit with where we are going. Task lighting balanced with ambient, ratio of ambient to task, or task to surround and background, reflectance versus absoptance, cubic illuminance versus cylindrical illuminance all sound familiar. In fact a good designer working with illuminance and reflectance, or luminance, exitance, and absoptance will be thinking about how the surfaces in a room will balance, how the light will flow, how much light is needed and how well the task is lit whatever that task may be.

My final problem with MRSE is the measurement. In real life we have to measure a room in a short space of time, often just before handover. The use of an illuminance meter may not be clever, but it is simple and quick. The use of a cubic illuminance meter could be relatively fast, but demands much more thought. The use of HDR imaging makes things far too complicated. We will have to define the viewpoint(s) and direction(s) for multiple measures, then blank out roughly the luminaires, and then calculate the MRSE. This set-up and post-processing will be simply too complicated to be accepted by our customers who already think illuminance measurement takes too long.

The problem is not one of method, it is one of process; the process of designing lighting involves many other practitioners, with many other priorities and few with a focus on the lit effect. The problem is not with 500 lx or task uniformity, we can change these numbers and most people would not complain (as long as they get lower). The problem with Kit's proposal is that it would demand a change in process and a lighting design profession who did all lighting design and integrated this with the architect and interior designer, so whilst the proposal is deserving of merit, we have a long way to go until it can be realised practically.

Comment 2:

MB Wilde (MBW Lighting)

My first 15 years of design were probably as a technocrat lighting engineer using prescriptive recommendations from the various Guides and Codes and applying them through predictive techniques to generally dump sufficient lumens onto horizontal planes to meet the prescribed visibility or performance illumination values.

Around 1975, I had a 'road to Damascus' event that showed me that this route of prescriptive and predictive design was fraught with problems, particularly in the office workplace, not the least of which is that of not knowing what the appearance of the space would be like until it was actually completed . . . and so often met with disappointment. It would achieve the various prescribed criteria, but fail miserably with its appearance.

I realised that knowledge and experience had to be led by visionary intent . . . that laws can only predict, they cannot create. I had to know and agree what space should look like and how it would operate from an end user point of view. From that time until now I have endeavoured to carry out lighting design based around an ethos of ambient, task/display . . . to separate and deal with each of these factors before combining them as composites to achieve an agreed spatial appearance with appropriate vision objectives.

In a career spanning 50+ years, I have seen no evidence that the visibility or performance route has led to either increased satisfaction or productivity in the workplace. In fact, often this approach has led to quite the reverse . . . dull, lifeless, non-motivational and disappointing spaces accompanied by continual complaints and moans from end users.

Moreover, this route when applied to offices, designing a horizontal illuminance of 300–500 lux from wall-wall, when the actual total task plane is probably less than 15% of net lettable floor area, and that this task plane is possibly never more than 50% in use because of occupancy patterns, has led to a gigantic misuse of energy (both embedded and consumed) over a considerable period of time! And, unfortunately, still does.

I both welcome and concur with the author's views that it is time to change from a basis of 'visibility' to one of 'appearance'. I would go further and say that in my view it is probably at least 30 years too late!

The idea of redefining the lighting of space in respect of two design criteria, perceived adequacy of illumination (PAI) and illumination hierarchy (IH) clearly captures the idea of lighting for ambient and task/display, an idea that has long been discussed by designers. It must surely be welcomed by any discerning designer. There have been previous attempts to devise predictive methods for 'appearance,'[1,2] none of which have ever found general usage.

Whether this reluctance was brought about by the complexity of operation and computation, laziness on the part of the designer, or reluctance to accept responsibility for design, we will never know. This last comment is driven from a paper I delivered at a British Council for Offices conference in 2004. I proposed a shift in design to an ambient/task/display philosophy and was met with opposition from a number of very senior Directors in Building Services Design companies that declared they would only ever do what was in the SLL Code for Lighting or the British/Euronorm Standards (horizontal illuminance)... because that is what was required of them by their Professional Indemnity Insurance, the Great God PII (the tail wagging the dog!!)

So with this history of 'reluctance', I do have concerns with the author's proposal. How many lighting designers or lighting engineers would actually use an appearance method, which by its very nature will require more complex calculations? Cuttle addresses this in his proposal, that we need new software programs to carry out this part of the predictive process. So a part of the development of his proposal must be discussions with lighting software developers such as Dialux, Relux, AGi32 etc. At least having the necessary software would reduce the risk of excuse from many lighting designers that it was too onerous and fee consuming!

Would the method proposed actually deliver a designers 'vision' or would it deliver an institutionalised vision formed by some technical committee or other. I say this in the anticipation that to be accepted nationally, the Lighting Institutions, Associations and Societies of each country would need to incorporate the methodology into Guides, Handbooks, and/or Codes.

At the moment I suspect very few designers would use the method proposed, except for perhaps a few exemplar projects. What does a designer do for the 'speculative' space. That space where its interior design, space planning and surfaces are unknown. Developers appear to be unbending in their desire to implement pre-tenancy agreement lighting fit out, letting tenants supplement with post tenancy agreement enhancements. Would they agree to a base level appearance scheme, one that could change dramatically as spaces are let? How would post tenancy agreement lighting enhancements inserted into pre-tenancy agreement lighting fit out modify or change responsibilities as to a design audit?

The author indicates Tables 1 and 2 to be approximate, and suggests that more research is necessary to develop a range of values that corresponds to peoples' expectations for the appearance of different categories of indoor space. I would agree that this is necessary, five MRSE values and four Illuminance Ratio values hardly instil confidence as a route to satisfactory appearance. A problem perhaps exists that if these criteria are over specified, many designers will continue the way they have for many years.... prescriptive criteria selection, calculation prediction (computer) and completely overlook their essential 'visionary' role in creating a visually satisfying and functional space!

The author is correct in his view that lighting design is split into two distinct camps 'appearance' and 'visibility'. I do agree with this view and it does raise a potential problem, in that, many in the 'appearance camp' are conceptualists and novate the technical workings to manufacturers. 'Credentialling' could perhaps resolve this problem. This is a discussion currently being held in USA and also UK, that all Lighting Designers hold and are qualified to discharge a level of professional responsibility, and that all designs are subject to audit.

I would urge the author to continue with the development of this appearance concept, but it does need to be 'sold' to the various lighting societies, associations and institutions if it is ever to get off the ground, perhaps its biggest obstacle for success. In this respect, it would seem appropriate during the next year or so to present this proposal to National and International Lighting Conferences and to lobby support for its inclusion into National Lighting Guides, Codes, Handbooks. The SLL is planning and calling for papers for its International Lighting Conference in Dublin April 2013, perhaps a venue for the author to get the ball rolling on effecting this much needed change in lighting design.

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Reply to comments:

C Cuttle

The positives in these two responses are notable. Macrae declares that he likes MRSE as a concept, and Wilde agrees that we need to switch from 'visibility' to 'appearance' as a basis for standards. Both discussers recognize that the current situation needs to change (Wilde considers it 30 years overdue!), but both see rafts of reasons why such change would be problematical, impractical, and simply unable to happen. Wilde cites examples of earlier attempts to rationalize lighting practice, all of which were dismal failures, and both seem to expect that this proposal has no chance of avoiding a similar fate. So let me see if I can suggest a brighter option.

Macrae sees 'the first problem' with MRSE to be that it demands 'an understanding of lighting . . . beyond that which most practitioners of lighting possess.' Well, what sort of a profession do we all see ourselves to be part of? If we are to accept that the only changes that can be considered as practical are ones that fall within the scope of those who, to use Wilde's phrase, 'dump sufficient lumens onto horizontal work planes to meet the prescribed visibility or performance illumination values,' then we have a bleak future indeed. Wilde describes a 'history of reluctance,' and questions how many lighting designers or engineers would use a method which, 'by its very nature will require more complex calculations?' Does the Lumen Method really push the mathematical skills of our designers and engineers to their limits? Think of our CIBSE colleagues who design air conditioning and sound systems in buildings – they deal with far more challenging calculations. To all this I would add that I teach Advanced Lighting Design at the Queensland University of Technology in Brisbane, Australia, and the students respond with enthusiasm to the concepts that I have covered in this paper (and more besides) but then some of them tell me that they doubt whether they will ever get opportunities to apply the concepts in their work. If we assume that people are not capable of anything more than mundane work, we are ensuring that that is all that will occur.

Wilde gives a chilling account of the 'very senior Directors in Building Services Design companies' whose lighting decisions are governed by professional indemnity concerns. The contents of the SLL Code and the EN Standards are seen by these people not just as frameworks within which lighting design options may be explored but as specifications to be rigidly applied. Even though the recent SLL Code refers to task planes without assuming them to be horizontal, it will take far more than that to change current attitudes. As Macrae says of the horizontal work plane (HWP), 'it just happens to be the easiest [concept] for the building industry to work and litigate with.' Easy it may be, but it bears no sensible relationship to illumination adequacy. My experience leads me to agree wholeheartedly with Wilde's observation that he has 'seen no evidence that the visibility or performance route has led to either increased satisfaction or productivity in the workplace.' Surely, we cannot continue indefinitely to accept this situation.

A few years ago, Howard Brandston and I taught the two Lighting Design Studios in the graduate lighting program at the Lighting Research Center, Rensselaer Polytechnic Institute, in New York. One of Howard's maxims was, 'First light the space; then attend to the details.' The details could be work-related tasks; or they could be retail displays; or artworks; or architectural details; or simply anything that deserves attention. This breaks away from treating every space to be lit as a workplace, or worse still as an office, and it is for this reason that I refer to details for attention as 'targets', not 'tasks'. Wilde asks, "Would the method proposed actually deliver a designer's 'vision', or would it deliver an institutionalised vision ..." and the answer is that it could do either. Let us imagine a space for which the prevailing standard specifies (or mandates) a minimum MRSE value of 150 lm/m^2. An individual could choose, or an institution could require, that the HWP be uniformly lit to, say, 300 lux. The designer/engineer would designate the HWP to be the target area and would set the target/ambient illuminance ratio (TAIR) to a value of 2. Entering these values into one of the updated lighting software packages that would (in this imagined situation) have become available would produce a quite unexceptional grid-plan luminaire layout fully compliant with the standard. So what is the point of making the change? The difference is that this lighting distribution has been chosen. A designer/engineer who is not so constrained could choose targets and TAIR values leading to different lighting distributions giving quite different appearances to the space and its contents, any of which could comply with the standard. An MRSE standard does not demand creative design, but it does not get in the way of it.

The world of lighting is in a spate of change. The impact of the new technologies for light sources and controls is massive. Society is changing in how it uses buildings (not just workplaces) and what it expects from its surroundings. The idea that we can persist with our 19th century notion of lighting visual tasks for productivity is untenable, but changing the standards will require concerted effort. This is a crucial step, not only for the reasons discussed but because it will set new curricula for lighting education programmes. We need young people who have been taught that devising lighting installations is an activity that requires thought. We need new research into how people assess illumination adequacy. We need to take a new approach to how we guide general lighting practice.