Equivalent Distribution of Natural and Artificial Lighting in the Interior Space

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Abstract. In this research, the classrooms of the College of Applied Arts in Baghdad were chosen as a model for studying the levels of illumination and the extent of their homogeneity in all points of space for four similar classrooms in terms of design. The readings obtained by measuring devices were compared with the required standards, where a large deviation of these readings was observed with general criteria due to the rotation of earth around itself. This leads to a change in the angle of sunlight falling on the windows of the interior space in one day for the period during which students were in these halls. Although natural lighting is important, by obtaining the ideal display factor of (1), it may be impossible to obtain this value by using artificial lighting in addition to the health and economic aspects. Therefore, the researchers suggested an electrical system consisting of sensors of the intensity of illumination distributed on multiple points regularly within the area. The internal space is linked to an electronic self-control panel, in a way that achieves a level of illumination and uniformity close to the required standards. This electrical circuit controls the automatic closing and opening of window blinds, which are made of metal strips or any other material chosen by the interior designer so that they move horizontally and vertically and change automatically in conjunction with the change of the angle of sunlight falling on the windows of the interior space. Each curtain is divided into parts and every part moves vertically and horizontally separately from the other part to cover a specific area of space in order to achieve the best state of homogeneity, with a level of illumination close to the general standards and for the total area of the internal space.

Keywords. Natural and artificial lighting.

1. Introduction
Many designers simplify the issue of lighting by calculating the number of lighting fixtures, the capacity and type of each installation using laws, forgetting that lighting contributes significantly to the comfort of a person and affects their activity. Equivalent distribution of natural and artificial lighting requires controlling the characteristics of lighting (such as to benefit from natural lighting or to choose an artificial lighting that displays colours as required). Also it requires, controlling lighting uniformity to overcome some disadvantages (such as glare) to meet the general standards of lighting. Therefore, this research examines the spaces of the educational halls at the College of Applied Arts in Baghdad as a model for
students’ need for psychological and visual comfort at the same time. The study explores advantages of natural lighting over artificial lighting, focusing on ways to take advantage of natural lighting by focusing on space windows and employing them to control natural lighting on a par with artificial lighting. The aim is to find appropriate proposals to approach the level of classroom lighting to the level of general standards. Indirect lighting can be used to obtain homogeneous lighting, provided that the colours of the surfaces of the walls and ceiling are light and matte, and that the intensity of illumination for general lighting in classrooms ranges between 250-200 lux. Also, for blackboard lighting, the intensity of illumination should not be less than 250 lux and that the permissible contrast ratio does not exceed 3:1 [1] between the board and the surrounding wall surfaces.

2. Characteristics of direct and indirect lighting
Architect (Richard Kiley) developed three principles that he considered as the foundations in lighting design, namely (Ambient lighting), to make people see the activity and place appropriately, (Accent lighting), to focus on certain elements and show them clearer than others to attract attention to them, and (Play) of brilliance to show off light as an aesthetic element.

We will focus on the characteristics of the first principle, which is public lighting, as it depends on the design of educational spaces, which, as is well known, is either direct or indirect lighting. Each type has its own characteristics, whether the lighting is natural and its importance from the visual, psychological, economic or artificial aspect, in natural lighting [2, 3].

A- Shadows are strong in direct lighting, while in indirect lighting, there are no shadows.
B- There is a big difference between the luminance levels when they are direct, that is, they are not homogeneous, while in indirect lighting we get a high degree of homogeneity.
C- The glare is high in direct lighting, and they disappear in indirect lighting.
D- A good stereoscopic (modelling) of three-dimensional objects is obtained when using direct lighting, whereas this modelling is not obtainable in indirect lighting [1, 4].

As for artificial lighting
A. A high electrical power is needed in direct lighting, and conversely in indirect lighting.
B. There is complete absence of glare when using indirect lighting if the design is good, while in direct lighting the glare is very high and it depends on the type of lighting installation.
C. The ceiling is not bright and therefore gives a feeling that the space is not lit in the case of using direct lighting, while in indirect lighting the ceiling is bright and thus the height of the space appears high if the lighting depends on the ceiling, but if it depends on the walls, the space appears to be wide.
D. Direct lighting does not depend on the colours of the ceiling and walls, and the shadows here are high, while in indirect lighting we depend on the colours, ceiling and walls, and the shadows are almost absent [1], [5].

3. Uniformity
When luminance level of (300 lux) is needed for a certain space, this means that the average value to be obtained is (300 lux), but different values will be obtained in that space. Some of these values are less and some are higher than the aforementioned value. Hence, the value of a factor homogeneity is depended, which represents the ratio between the minimum value of the level of illumination and its average value, which should not be less than 0.5 in spaces where we do not need shadows. In offices a smoothing factor of not less than 0.7 is required [6].

4. Glare
It is a high contrast in the levels of luminance. It is of two types:
A. Disability Glare.
It is the glare that obstructs the vision, and it is often in the outer places that things cannot be seen with.
B. Discomfort Glare.
This type is less severe than the first type, and it is what we are interested in because it occurs in the internal spaces and is divided into two types: direct glare, whose source is the lighting structures directly on the eye, and the reflected glare, which is reflected from the high-gloss surfaces, making the vision difficult and uncomfortable. To overcome it, appropriate lighting compositions must be chosen in correct places or indirect lighting should be used [7].

4.1. Blocking direct glare from lighting fixtures
The glare is reduced for the lighting structures by blocking the upper part through the reflector as in Figure 1.

Figure 1. Shows the glare-blocking of illumination compositions [1].

Figure 1. Shows the glare-blocking of illumination compositions [1]. The light produced between the angles 45˚ and 85˚ is what disturbs people in the inner spaces, and if the light is blocked or reduced in this part of the lighting structures, its brightness will be little; 45˚ for a standing person as in Figure 2.

Figure 2. Shows the angle of the human field of vision in the normal state [1].

Therefore, international specifications set a standard called (Unified Glare Rating) (UGR)) to determine the limits of glare in interior lighting. This factor depends on the color of the ceiling and walls, as well as the brightness of the lighting structures and the location of the direction of vision in the inner space.

\[
UGR = 8 \log \left( \frac{0.25}{L_b} \sum \frac{L^2 \cdot \omega}{p^2} \right)
\]

(1)

Where; \(L\) = The luminance value of the luminaire, \(L_b\) = The value of the background luminance, \(\omega\) = The solid angle of the luminaire that is seen by the viewer, \(p\) = The Guth Index. Based on the likelihood of glare, also known as Visual Comfort Probability, and \(\Sigma\) = Shows that the equation (shown above) includes all the fittings located within the area. The permissible values of the uniform glare factor for some applications are shown in Table 1. The uniform glow factor of LEDs is shown in Figure 3.
Table 1. Shows the permissible values of the glare factor

| Application                      | The maximum permissible value of UGR |
|----------------------------------|--------------------------------------|
| Exact engineering drawing offices| Less than or equal to 16              |
| Offices                          | Less than or equal to 19              |
| Real factories                   | Less than or equal to 22              |
| Heavy equipment factory          | Less than or equal to 25              |
| Train stations                   | Less than or equal to 28              |

Figure 3. Shows the values of the uniform glow factor of LEDs [1].

5. The degree of colour rendering

The best light source for seeing things with their natural colour is undoubtedly sunlight. Hence, the source of natural light is considered the standard for true colours and the colour rendering property is $Ra = 100$ and light bulbs are compared to it. For example, if there is a light bulb that has a degree of colour discrimination $Ra = 80$, it means that it distinguishes colours by 80% compared to natural light. This is a very important criterion for selecting suitable light bulbs for the appropriate application [8-9]. There are many types of lamps, including lamps that have a high degree of colour discrimination of up to $Ra = 100$ such as halogen lamps, and some lamps have a low degree of colour discrimination of up to $Ra = 60$ or even less [10-12]. The degree of color discrimination for different types of (LED) lamps and the halogen lamp is displayed in Table 2.

Table 2. Shows the degree of color discrimination for different types of LED and halogen lamps.

| Light source                              | CCT (K)   | CRI |
|-------------------------------------------|-----------|-----|
| High–CRI LED lamp (blue LED)              | 2700-5000 | 95  |
| Ceramic discharge metal-halide lamp       | 5400      | 96  |
| Ultra-high-CRI LED lamp (violet LED)      | 2700-5000 | 99  |
| Incandescent/halogen bulb                 | 3200      | 100 |

The characteristics of some lamps are displayed in Table 3.
Table 3. Shows characteristics of some lamps.

| Feature             | Halogen | Metal Halide | Fluorescent | Built-in fluorescent | LED |
|---------------------|---------|--------------|-------------|-----------------------|-----|
| Efficacy            | 22      | 90           | 95          | 77                    | 90  |
| Brilliance          | Appropriate | Appropriate | inappropriate | inappropriate | Appropriate |
| Accent              | Appropriate | Appropriate | inappropriate | inappropriate | Appropriate |
| Dimmable            | Appropriate | inappropriate | Appropriate | Appropriate | Appropriate |
| Average life        | 3000    | 12000        | 18000       | 12000                 | 50,000 |
| Color rendering     | 100%    | 90%          | 88%         | 82%                   | 95%  |
| Color temperature   | 3000    | 3000-4000    | 2700-8000   | 2700-8000             | 2700-12000 |

6. Procedures, tests and results analysis

A. Classrooms (33, 34, 35, and 36) were selected. They are located in the middle floor of the building, which consists of three floors and this represents the middle state for the angles of sun rays falling on the building. Classrooms (33 and 36) are located directly opposite to the sun rays fall and there were not any trees or neighbouring buildings, while classrooms (34 and 35) are located in the other side which is not opposite to the sun rays falling on some neighbouring buildings. Nine points were determined, three of them are near the windows, three are far from the windows and the last three points are located in the middle. This distribution results in three points near the board, three far from the board and three in the middle in a regular manner covering the students sitting area as shown in Figure 4.

![Figure 4. Shows the classrooms locations.](image-url)
B. Using a Lux Meter, the illumination level of the nine specified points in each of the four halls that were selected was measured at 9 am with only natural lighting, and then the measurement was repeated in the presence of natural and artificial lighting.

C. The procedure described in Paragraph B above was repeated, but at 11 am and at 1 pm, since these times (1, 9, 11) are within the period of students' attendance to receive educational lessons, as shown in Figures 5, 6, 7, and 8.

**Figure 5.** show the Change of luminance level over time for the classroom(33)

**Figure 6.** show the Change of luminance level over time for the classroom (34)
7. Results and discussion
First of all, it should be noted that the four halls were tested on the first floor, as it represents the middle floor because the building consists of three floors (NOTE: In American English, the middle floor in this case is called the second floor, if you are writing in British English, then ignore this note). This makes the readings of the level of lighting intensity close to the average reading for the three floors and for the same point, moreover, the location of each of the two halls (33 and 36) makes its windows directly opposite to the sun rays during the students presence, as they are surrounded by an open green space, making the natural lighting of the two halls almost direct. (Please observe spacing between paragraphs). However, the natural lighting of each of the two halls (34 and 35) is indirect, because their windows are located on the opposite side of the sun rays fall, and they are overlooking a lighthouse surrounded by walls on four sides. Since the main goal when lighting the educational halls is to obtain uniformity in all points of space, we noticed from the first look at the illumination level diagrams for all halls that there is no homogeneity. Thus, by calculating the homogeneity factor for all halls, as shown in the table below, we noticed that its value is out of the standards. Its value should not be less than 0.5 except for three cases only, in which the level of illumination was out of the standards required for educational halls, which is limited between (300-500 lux). The uniformity coefficient for the four studied classrooms are tabulated in Table 4.
Table 4. Listed the uniformity coefficient.

| Classroom No | Natural & artificial lighting at 9AM | Natural lighting at 11AM | Natural & artificial lighting at 9AM | Natural lighting at 11AM | Natural & artificial lighting at 9AM | Natural lighting at 11AM | Uniformity Coefficient |
|--------------|------------------------------------|-------------------------|------------------------------------|-------------------------|------------------------------------|-------------------------|------------------------|
| Classroom 33 | 0.44                                | 0.26                    | 0.42                               | 0.29                    | 0.14                               | 0.29                    | 0.44                   |
| Classroom 34 | 0.35                                | 0.47                    | 0.57                               | 0.28                    | 0.48                               | 0.29                    | 0.35                   |
| Classroom 35 | 0.5                                 | 0.44                    | 0.54                               | 0.36                    | 0.48                               | 0.27                    | 0.5                    |
| Classroom 36 | 0.3                                 | 0.13                    | 0.44                               | 0.49                    | 0.22                               | 0.12                    | 0.3                    |

If we consider the level of natural lighting, and this is what concerns us for all points with the change of time, we notice in rooms (33 and 36), whose windows are in opposition to direct sunlight, that the values of the level of illumination vary with the change of time and the locations of the measurement points change. In most cases, they are close to or exceed the values of the general standards of lighting. Whereas in the two halls (34 and 35), located on the opposite sides of the sun rays fall, it is noted that the values of the level of natural illumination are less than those of the first case. However, they are sometimes close to or exceed the values of the general standards of illumination. In regard to the values of the points that are less than the values of the general criteria, they were more than the first case as well. In hall (35), the values were better than those of hall (34) due to the different angles of incidence of the reflected light rays. It is also noted that the values of the illumination level were high in the two points (3,9) of the two halls (33,36), exceeding (3000 lux) because they are near the windows facing direct sunlight, causing an uncomfortable glare in those points. It is also noted that the level of illumination is specified in accordance with the general standards in point (3) of the hall (35) and this, as mentioned earlier, is due to the angles of reflection of light from the walls adjacent to the windows, and it is less than that of point (6) of the hall (34) for the same reason as well. As for artificial lighting, its effect was limited for most of the measurement points of the above-mentioned axes, which drives the researchers to look for methods to benefit from natural lighting as much as possible, as it is distinguished from artificial lighting in several aspects, whether in the visual, psychological or economic aspect, by addressing the problems and weaknesses mentioned above.

8. Suggested remedies and solutions
First, focus should be directed to finding ways that enable us to make the most of the natural lighting and avoid the problems resulting from it. Therefore, the researchers focused on space windows and how to control the entry of sunlight through them. The researchers suggest using the following:

1. Curtains made from metal strips or other materials that meet the purpose, with one side being a good reflector of light to be controlled electronically so that each slice revolves around itself, whether vertically or horizontally, in order to control the direction of the incoming light and its reflections inside the space through a control panel, as shown in Figure 9.
1. Light sensors distributed uniformly to sense the intensity of light and cover the total area of space.
2. LED lighting fixtures can be dimmed and recharged.
3. An electronic control panel linking curtains, light intensity sensors, and lighting fixtures.

The proposed design for the classroom (36) also applies to the other halls (33, 34, and 35), since the four halls are similar and the design idea can also be applied to any interior space as shown in Figure 10.

![Figure 10. Shows the real photo of hall 36.](image)

Through this system, the amount and direction of the natural light required to illuminate the space is controlled and distributed uniformly on all parts of the space based on the required standards (300-500 LUX), in a manner that ensures the elimination of direct and indirect glare, provided that artificial lighting is used exclusively when needed. The dimensions of the classroom (36) are (9 m in length, 6 m in width, and 3 m in height) and it has two windows (the first with dimensions of 1.2 m and 1.8 m, and the second with dimensions of 2.4 m and 1.8 m). According to the proposed design, the ceiling area of the classroom was divided as shown in Figure 11. The proposed curtain with metal slats for the first window was also divided into two parts, while the second window curtain was divided into four parts, since its area is twice as the area of the first window, as shown in the previous figure. Hence, part A of the curtains is responsible for the amount of light and the angle of its fall on part A of the classroom ceiling based on instructions from the control panel, which receives signals from the light intensity sensor of the A part of the ceiling in a manner that achieves the required values according to the general standards of illumination. In the event that the system is unable to achieve a natural amount of light that matches the standards, the dimmable LED lighting installation of the A part is used in the same manner of lighting the rest of the parts. By lighting the ceiling, indirect natural lighting is obtained, thus achieving uniformity with lighting, as well as getting rid of obstructive glare caused by sunlight. It is also possible to add solar cells to the system in the case of using combinations of rechargeable lighting.
9. Conclusions
1. Using curtains with shutters that move in two directions (x, y) should be avoided, instead those with shutters moving in one direction are used.
2. Do not taking advantage from natural lighting as required, but depending always on artificial lighting.
3. In cases of using natural lighting, ignorance of UGR and uniformity in space lighting is noticed.
4. Most classrooms do not contain smart lighting system.

10. Suggestions
1. Conducting a study about the possibility of making curtains with shutters that can move in three directions on three axes (X,Y,Z) in order to increase the ability to control the natural light that pass through the internal space.
2. Conducting a study about the possibility of inclusion the movable curtains lighting cells to support the artificial lighting inside the space.
3. Using smart lighting systems in classrooms to benefit from natural lighting as much as possible.
4. Using indirect lighting in classrooms in order to avoid most lighting disadvantages.

Figure 11. The proposed design for classroom 36.
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