ENERGY EFFICIENCY IN OFFICE BUILDINGS: LIGHTING SECTOR

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ABSTRACT

Efficient utilisation of energy is considered to be one of the main tools of controlling the ever increasing demand for energy, especially in developing countries where there is a large potential for improvement. In recent times, the efforts to improve efficiency have been largely concentrated in the electricity sector mainly due to its rapid growth in the developing nations, which is as high as 8% to 10% annually.

The broader objective of this study was to develop "building codes" addressing the energy efficiency aspect within commercial buildings considering areas such as thermal comfort, lighting and other building services. This included deriving electricity requirements for different activities such as air-conditioning and lighting, giving due emphasis to different tasks performed within different types buildings. It has considered the fact that lighting and thermal comfort levels required by people in different countries differ depending on the type of environment they are generally exposed to.

The paper describes the studies carried out to address the lighting sector of office buildings covering different tasks, with recommendations for optimum lighting levels to perform these tasks in Sri Lanka. These studies included assessing visual performance of people involved in different activities under varying illumination levels in a controlled environment and a comparison of these optimum lighting levels with international standards. It could be seen that the required optimum lighting levels are generally lower in Sri Lanka which is likely to be the case in many developing countries thereby clearly emphasising the need to adopt their own lighting standards in turn helping improved energy efficiency within buildings.

1.0 INTRODUCTION

The annual electricity demand growth in Sri Lanka over the next 20 years is estimated to be about 9% [1]. Presently almost all the possible large-scale hydropower generating facilities are being utilised to their maximum. Therefore, the increasing demand will be supplied by increasing thermal power generation using coal or petroleum as fuel. Increasing thermal power generation will result in rise in the unit cost of electricity supplied while increasing the adverse environmental impacts. Considering the social, economic and environmental issues associated with these impacts, the importance of efficient utilisation of electrical energy can be emphasised. A major part of the entire electricity consumption in industrial, commercial and services sector, is primarily due to artificial lighting and other services in buildings. Therefore efficient utilisation of energy for lighting will reduce the maximum demand and the total electricity consumption of these consumers. The efficient use of energy in lighting designs should focus on the following.

Selection of

- appropriate illumination levels
- efficient lamps and associated electrical control gear and
- appropriately designed luminary systems.
- efficient levels of natural lighting

Presently building designers and architects follow international standards and guidelines on their designs. It is common knowledge that, the selected illumination level should be sufficient to satisfy the requirements of people who occupy that environment when performing a given task. The desirable illumination levels required by different people is dependent on the degree of complexity, the level of concentration and overall skills required on the task to be performed. It will also be affected by the climatic conditions of the immediate vicinity. In order to ascertain whether a given illumination level is sufficient or in general whether the lighting level is acceptable, it is required to consider the quantity and the quality of the illumination provided. The quantity of light provided refers to the optimum amount of light required to efficiently perform a specified task such as reading, writing, cutting, cooking and eating. Similarly, the quality of light needs to be such that it is free from glare with good colour rendering properties.

In most commercial buildings in Sri Lanka, the illumination level is usually below the typical design level used. It is evident that the illumination level appropriate for a tropical country like Sri Lanka is quite different from the standard values specified in the CIBSE (The Charted Institution of Building Services Engineers) or IESNA (Illuminating Engineering Society of North America) guidelines. This highlights the necessity of having an appropriate set of guidelines and code of practice on the selection of illumination levels for different premises and associated tasks. Any reduction of the lighting levels from the present levels that are being used results in savings on energy consumption as well as capital expenditure for lighting luminaries.

Employment Distribution

The total employed population in Sri Lanka is estimated at 5.6 million consisting of 3.9 million (69.2%) males and 1.7 million (30.8 percent) females. While 0.8 million (14.4%) of this reside in urban areas, 4.8 million (85.6%) live in rural areas [2]. The distribution of the currently employed population considering their major occupational group is given in figure 2.1.

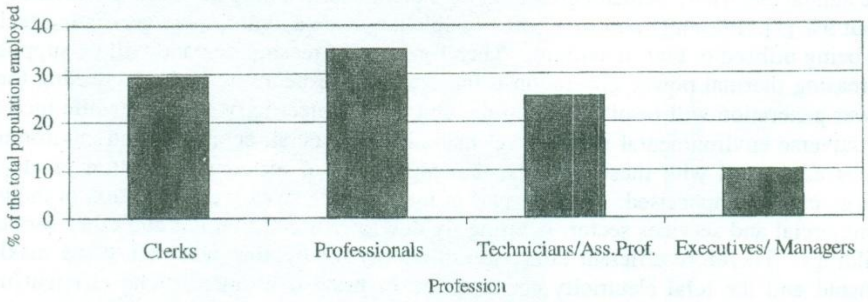

Figure 2.1 - Percentage distribution of currently employed population by major occupational groups.

2.0 RECOMMENDED ILLUMINATION LEVELS

The existing illumination levels used by certain European countries in office premises are given in Table 3.1 and 3.2. While recommended levels for other countries such as USA and UK are 1500lux and 600lux respectively, Russian levels vary from 50lux to 150lux respectively. In the recent past, the increased concern for energy conservation has led to the lowering of these recommended levels in USA.

Description - task	France (lux)	Germany (lux)
General offices	320	500
Typing offices	480	500
Computer rooms	-	500
Drawing boards	800	1000

Table 2.1 - Recommended interior lighting levels in Lux, for France and Germany (1973).

Description - task	Lux
rough tasks, large details	200
lift, kitchen, dinning room, library, casual reading, lecture room, ordinary tasks, medium detail, general office, typing, control panels, drawing office	400
fairly severe tasks, small detail, computer room, dress making, needlework, art room	600

Table 2.2 - Recently recommended illumination levels in United Kingdom.

3.0 METHODOLOGY

A sample representing the entire population employed in office environment was selected to study the visual performance under different illumination levels. They were subjected to a standard test developed by 'Weston'*, one of the most widely used methods of investigating the effects of lighting on work. This involves performing a simple task with a chart, which has the critical details easy to identify and measure, known as the 'Landolt ring' chart shown in Figure 3.1. The test is described in detail later.

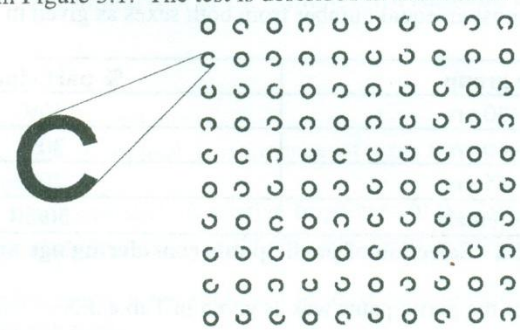

Figure 3.1: Landolt ring' chart

* first attempt to produce a model of the effects of light on work was made by Beutell in 1934

Tests were carried out in a simulated office environment under controlled conditions. In order to assess the visual performance, the background brightness, glare and illuminance need be reduced to the minimum possible level. Therefore the controlled environment was created in a special enclosure where the interference from external sources were minimised.

Simulated office environment

The enclosure made of tubular steel measuring 5m x 5m and height of 2.5m was covered with a thick white cloth. From outside it was covered with black polythene. The lighting system consisted of 8 ceiling recessed 2 x 36W fluorescent luminaries with clean prismatic diffusers. The control gear with electronic ballast was regulated using a potentiometer to provide a variation of the lighting levels from 0 Lux to 1000 Lux. Six tables with a height of 0.85m from the ground level were arranged for participants and the enclosure was fully air-conditioned with temperature and humidity maintained at 29C and 79% respectively.

Selection of participants

Participants were selected considering their social background and climatic conditions of different part of the country. Since the desirable illumination levels expected by different people are related to their nature of work involved, participants were selected from different occupational groups such as, clerks, computer operators, draughtsmen, executives engineers, proof readers, printing-press assistants, type-setters. They represented different state and private sector establishments such as banks, accountancy firms, architectural firms, corporations, law firms and news paper offices. The areas identified for the selection of these participants are given in Table 3.1.

Zone	Description	Area
1	Highly developed areas	Colombo
2	Relatively less developed areas	Kandy, Kurunegala, Matara and Nuwara - Eliya
3	Recently electrified areas	Mahaweli settlements - Thambuttegama
4	Non-electrified areas	Monaragala

Table 3.1 - Selection of participants considering the social standards and climatic conditions of the country.

All participants were randomly selected from three age groups, 21-30 years, 31-40 years, 41-55 years, and almost an equal number from both sexes as given in Table 3.2.

Age group	% participants
20 - 30 yrs	50%
31 - 40 yrs	30%
41 - 55 yrs	20%
male/female	50/50

Table 3.2 - Selection of participants considering age and gender.

Final composition of the participants was as given in Table 3.3.

Description	Area	Number of participants
Highly developed area	Colombo	103
Relatively less developed area	Kandy	06
Relatively less developed area	Kurunegala	06
Relatively less developed area	Matara	05
Relatively less developed area	Nuwara - Eliya	06
Recently electrified area	Tambuttegama (Mahaweli area)	06
Non - electrified area.	Monaragala	06
	Total	138

Table 3.3 – Geographical Participants selected for the study.

It was decided that a maximum of participants would be limited to 6 in a test session comprising, three clerks, one typist, one computer operator and one executive. This composition was modified for architectural firms, printing offices where draughtsmen and typesetters were introduced.

Candidates of the selected sample were lumped in to different categories and the comparison with the national level data is given in Figure 3.2 below.

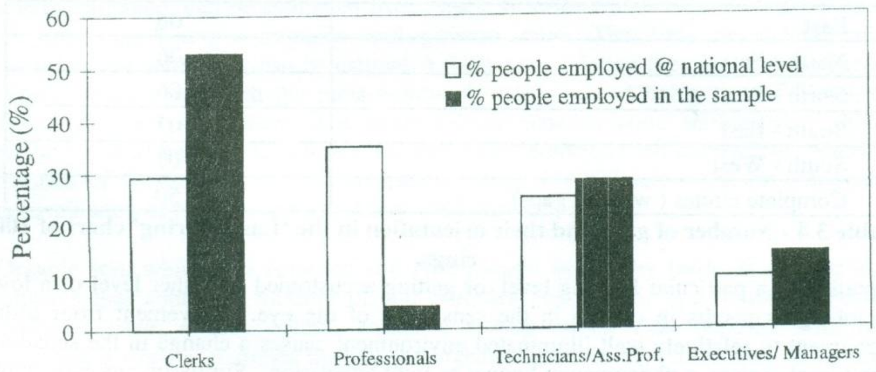

Figure 3.2: Comparison of the Sample with National Level Data

Opthalmological testing

Generally vision will be affected due to

- Human factors such as optical performance of age, colour perception and general condition of eyes, and
- Environmental conditions such as relative brightness of the task and surrounding glare from the task, relative movements of the task and previous experience.

Therefore all the participants were subjected to an opthalmological test to examine near vision, colour vision and fungi.

Visual performance test

The 'Landolt ring' chart has rings of shape C arranged in a matrix. The matrix can be 10x10, 15x15 or 20x20. Some of these rings have a gap oriented in one of the eight cardinal directions of the compass. Two Landolt ring charts were utilised comprising 100 rings in a 10 x 10 matrix and 400 rings in a 20 x 20 matrix. The chart containing 100-rings consisted of those oriented in 8 cardinal directions given in Table 3.4.

The composition of rings in the 400-ring chart is four times that of a 100 ring chart. The test comprised of two sessions consisting of six different illumination levels starting from 100Lux. These illumination levels, 100Lux, 150Lux, 200Lux, 300Lux, 500Lux and 750Lux, were taken as specified in the CIBSE service illumination scale. Adjacent illumination levels were selected so that they vary by approximately a factor of 1.5 mainly to provide a noticeable difference in the illumination levels. These levels were varied from 100Lux to 750Lux.

Gaps oriented in the direction of	Number
South	06
West	06
North	06
East	06
North - East	06
North - West	06
South - East	07
South - West	07
Complete circles (without gaps)	50

Table 3.4 - Number of gaps and their orientation in the 'Landolt ring' chart of 100 rings.

Adaptation to a particular lighting level, or getting accustomed to higher level or a lower level of lights results in change in the sensitivity of the eye. Movement from a dark environment to relatively well-illuminated environment causes a change in the sensitivity of the visual system, a phenomenon known as light adaptation. Similarly, any movements from a brightly illuminated environment to darker environment results in a change in the sensitivity of the visual system known as dark adaptation. During the selection of the lighting levels for the test it was necessary to consider that *light adaptation* period generally about one minute is far less than *dark adaptation* period which is about one hour [7].

They were expected to scan a matrix of Landolt rings and indicate the number of gaps oriented in a specific direction under different illumination levels. They were given a specified time duration for counting and the number of errors made were recorded. This process is known as the paced Landolt- ring task. At the end of each stage the illumination level was increased to the following level. An adaptation time of approximately a minute was allowed before repeating the test under the new illumination level.

4.0 RESULTS AND ANALYSIS

During the test, the illumination levels were increased within a wide range from 100 Lux to 750 Lux. It was expected that the participants would perform at best based on their individual likes and dislikes. Hence, the participants would record their minimum number of errors under the most preferred illumination level.

The number of errors made under different illumination levels were analysed considering the percentage errors made, and their mean values for varying illumination levels. This variation given in Figure 4.1 shows that the minimum had been recorded at an illumination level around 350Lux. As the illumination level increases from 100 Lux to 350 Lux, a significant reduction in the mean error can be observed. This can be attributed to better readability resulting from improved illumination. However, further increase in the lighting level shows a rapid increase in the mean error, which can be due to the effect of excessive illumination.

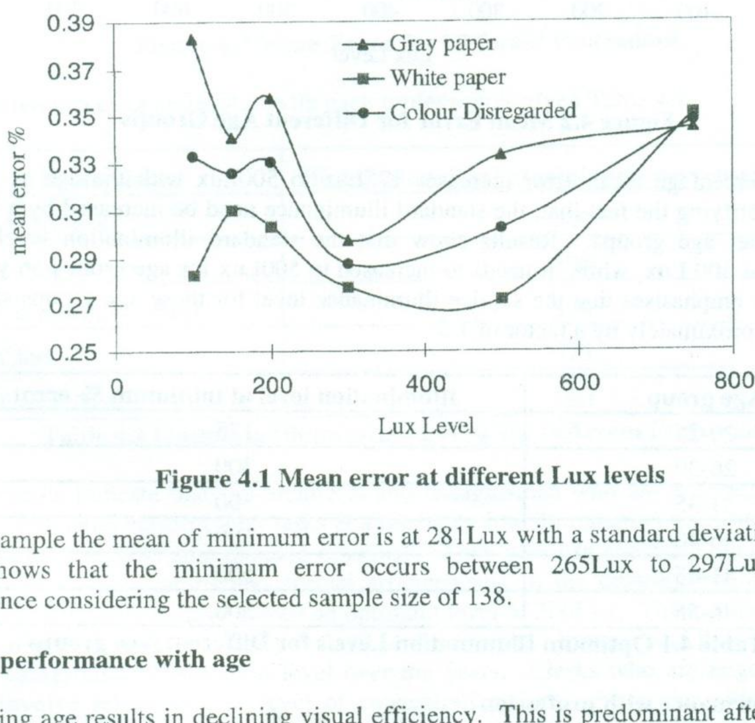

Figure 4.1 Mean error at different Lux levels

In the sample the mean of minimum error is at 281Lux with a standard deviation of 16Lux. This shows that the minimum error occurs between 265Lux to 297Lux with 95% confidence considering the selected sample size of 138.

Visual performance with age

Increasing age results in declining visual efficiency. This is predominant after 40 years of age, mainly due to the reduction of clarity of the vitreous humor and changes in the retina [5]. Therefore people with these visual disorders will require more illumination than under the normal circumstances. This can be seen in Figure 4.2 where the percentage mean errors are given for different age groups.

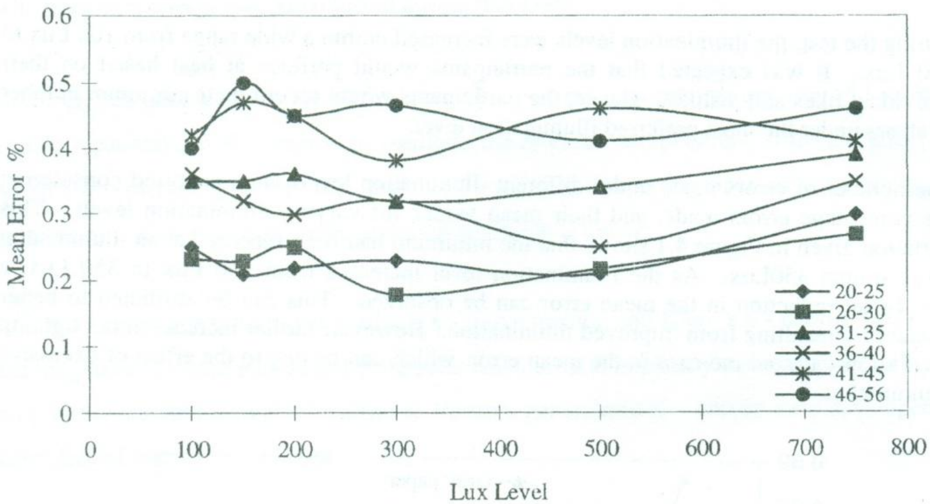

Figure 4.2 Mean Error for Different Age Groups

Minimum percentage mean error increases 175Lux to 500Lux with the age as given in Table 4.1 justifying the fact that, the standard illuminance need be increased by a factor of 1.5 for higher age groups. Results show that the standard illumination level can be maintained at 300 Lux while it needs to increased to 500Lux for age groups 36 years and above. This emphasises that the service illuminance level for these age groups should be increased approximately by a factor of 1.5.

Age group	Illumination level at minimum % error
20-25	175
26-30	300
31-35	300
36-40	500
41-45	500
46-55	500

Table 4.1 Optimum Illumination Levels for Different Age groups

Visual performance with profession

The type of occupation would describe the critical nature of visual component based on the degree of complexity, the level of concentration and overall skills required on the task to be performed. Reading, writing, computer usage, performing surgery, assembly of minute electronic components, brick laying, heavy machinery usage can be categorised as some of the different visual tasks. The mean percentage error was analysed under different professions. The variation of performance is given in Figure 4.3.

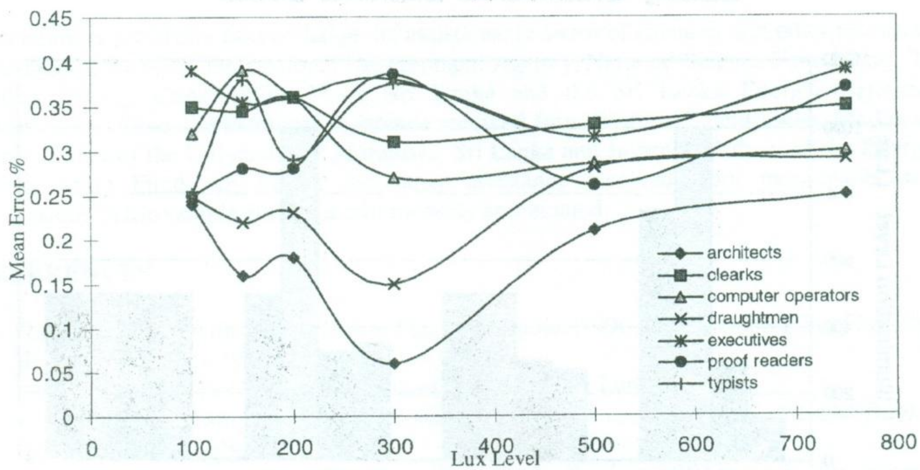

Figure 4.3 Mean Error for Different Professions

Minimum mean error associated with each profession is given Table 4.2.

Profession	Illumination level at minimum percentage error
Architects	300
Draughtsmen	300
Computer operator	300
Clerk	325
Executives	500

Table 4.2 Optimum Illumination Levels for Different Professions

These results indicate that the architects and draughtsmen who are engaged in the same professional arena perform their tasks at a relatively low illumination level of 300Lux even though they deal with fine detailed drawings. They also use special luminaries for their work, such as table lamps and special arrangements in the drawing boards. Similarly computer operators too have shown an optimum level of 300Lux. This can be attributed to the fact that they work constantly in front of the computer monitor and they have got used to this background illumination level over the years. Clerks who are engaged in tasks, which involve relatively low level of concentration, have shown an optimum level of 325Lux. However, the tests have indicated that the executives expect an optimum level of 500Lux though their natural work style do not demand eyes to be focused on fine detailed documents. This may be attributed to them getting used to generally over illuminated environment of executive offices. Comparisons of lighting requirements [3,4],are given in Figure 5.1

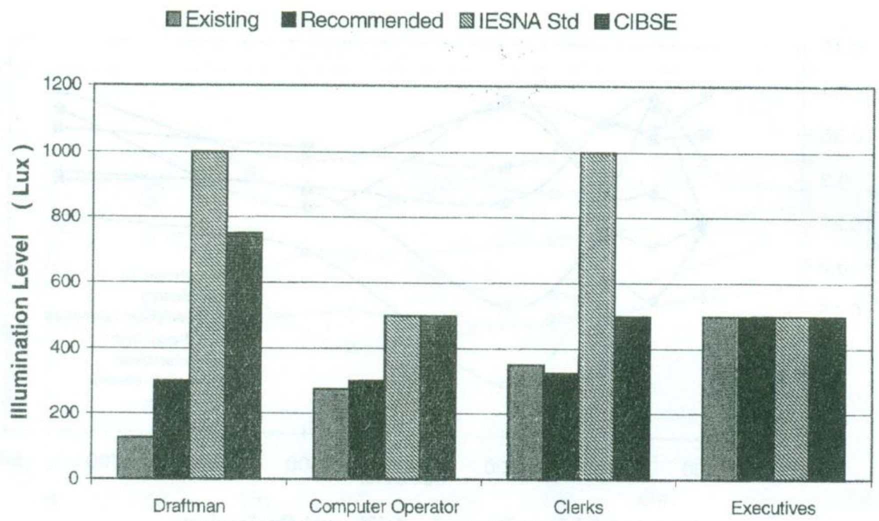

Figure 5.1 Comparison of the results

5.0 CONCLUSIONS

Analysing the results of this study, it can be concluded that the standard illumination level of office buildings can be brought down to 300 Lux from the presently used level of 500 Lux. Once the appropriate levels are standardised, their effectiveness should be analysed periodically and necessary adjustments should be made.

The results of the study indicate that the following illuminance levels for different professions recommended as appropriate levels.

Profession	Recommended Illumination level
Architects	300
Draughtsmen	300
Computer operator	300
Clerk	325
Executives	500

These recommended levels, essentially bring down the existing lighting levels in related office environments which will in turn reduce energy consumption in the lighting sector.

Taking in to account the experiences of the industrialised countries, such standardisation of lighting levels will reduce energy consumption by 20-40% or even more. However, past experiences show that such magnitude cannot be achieved within a very short period of time.

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