CHAPTER II

REVIEW OF LITERATURE

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Good lighting is necessary if work is to be done well and in comfort. It must help people to see the details of their work with the greatest possible speed and clarity, it must provide safe and congenial working conditions and it must be easy to maintain and inexpensive to run (Galer, 1987). According to Rea (1998) illumination must function to support (i) acquisition of visual information (ii) communication of information (iii) biological functions and (iv) avoiding hazards of illumination through sunlight. The Phillips Lighting Manual (1993) highlighted upon three primary lighting objectives, namely, visual performance, visual comfort and pleasantness, and energy and cost effectiveness. Visual performance is the term used to describe both the speed at which the eyes function and the accuracy with which a visual task can be carried out. Boyce (1998) identified three factors that influence visibility and hence determine the visual performance.

(i) Characteristics of the eye : retinal image quality.

(ii) Characteristics of the visual task : visual size of the task, and luminance contrast and colour contrast.

(iii) Characteristics of the light : lighting level, luminance distribution, glare and colour of light.

Practical experience in lighting engineering has shown that lighting recommendations for working interiors based solely on visual performance parameters are often inadequate. The 'standard' visual task simply does not exist. Most practical visual tasks are complex and differ from one interior space to another. As a result of investigations into the subjective assessment of illuminance and luminance levels, it is recognised that the degree of visual satisfaction in terms of comfort and pleasantness created by the lighting is an important, additional design consideration in all types of environment. The third major lighting objective is to provide lighting that fulfills the quantitative and quality standards, with the minimum usage of electrical energy. This can be achieved by applying an energy-effective design approach to lighting installations.

Each of the above mentioned aspects of lighting are discussed in this part of the chapter. In addition, a simultaneous presentation of the related researches is made.

1.0 CHARACTERISTICS OF THE EYE

1.1 The physiology of vision

When light falls upon the retina it acts as a stimulus to the rods and cones which serve as the sensory nerve endings. Stimulation of the retina by light causes visual sensations; upon these sensory cells and the images of objects in the outside world are focused by the dioptric system of the eye. Light falling upon the retina, however, causes two essential reactions, photochemical and electrical. The photochemical reaction initiates the visual process and gives rise to the changes in electrical potential which are transmitted through the bipolar cells to the ganglion cells and along the fibres of the optic nerve to the brain.

The eye is an optical system capable of producing within itself an image of an external object. The section through a human eye is shown in Appendix IV Plate 9 and in many ways working of the eye resembles that of a camera. When the normal human eye is at rest, it is focused on distant objects with the ciliary muscle relaxed and the lens flattened. When it is desired to focus nearer objects the ciliary muscle is contracted, thus allowing the lens a greater degree of convexity and changing its focal length. This process, which is of course largely involuntary, is known as "accommodation". It also includes some simultaneous movement of the iris which contracts when the eye is focused on near objects, thus allowing less light to enter the eye but providing a sharper image on the retina. Such an image is involuntarily focused at the fovea where the preponderance of cones assists the discrimination of fine detail.

The function of the iris in controlling the effective size of the pupil is chiefly performed under conditions of varying light intensity, when it allows the eye to function both in good light and bad. When the illumination is reduced to a low level the pupil opens wide; conversely, when the illuminatination is increased, the pupil contracts. This process, known as "adaptation", is accompanied by photo – chemical changes in the retina. The rods contain a liquid, called "visual purple", which is essential to vision and which bleaches rapidly under the action of light. An alteration in the of regeneration of this fluid must accompany the changes in the size of the pupil. This adjustment takes time, and the period which may elapse before the process of adaptation is complete may be considerable , particularly when passing from a high level of illumination into comparative darkness. This delay can cause temporary disability of vision, but when changes in illumination are gradual the process of adaptation continues without conscious knowledge.

Whilst the eye is capable of giving satisfactory results under the most adverse conditions, it should not be deliberately misused or the fine balance will be destroyed and some defect of vision will result. The illuminating engineer, therefore, in his efforts to provide good seeing conditions, is not only contributing to visual comfort and efficiency, but also seeking to safeguard the organs of sight.(Hewitt, 1952).

Age and Visual Performance

Vision is affected with age due to the natural physiological changes in the eye. The problems of decreased visual function with age relates to loss of accomodative power, absorption of light due to yellowing of lens, changes in the ocular media and losses of retinal transmission and sensitivity. With advancing age the vividness of blues and short blues becomes mutant and combined with scattering of light in the eyes, light becomes less distinct. This results in colour distortion, and reduced sensitivity to contrast (Rea, 1998).

Hopkinson and Collins (1970) and Rodgers (1983) pointed out that although an increase in illumination can reduce the impact of age-related changes in visual performance, too much of light can be undesirable since sensitivity to glare also increases with age due to changes that take place in the eye which results in more light being scattered in the optic media. Therefore, the changing visual needs of senior people should be taken into account while planning lighting for them. Elderly people need more light and at the same time are extremely sensitive to glare, thus the luminaires used should be properly shielded. Boyce (1998) indicated that catastrophic changes in the eye takes place with age which are basically concerned with optical and neutrological changes. When transiting from lit interior to dark outdoor or vice versa, it takes longer for elderly to adjust their visual system. On similar lines, Sanford (1998) suggested the use of dimmer system to create a comfortable transit between the interior and exterior space.

A number of experimenters have investigated the course of visual depreciation with age, and changes in the relationship between illumination and visual efficiency with age. The quantitative parameters of lighting was the primary focus of the researches carried out in the past. However, the qualitative aspect of lighting for the elderly has been explored only in the recent years.

Fortuin (1948) showed that if the light requirement for reading good print at ten years of age is put at 1, then the light requirement values are 1.5 times at 20 years of age, 2 times at 30 years of age, 3 times at 40 years of age, 6 times at 50 years of age and 15 times at 60 years of age. Weston (1948 and 1949) found that men about 25 years old can recognize printed objects quickly with an illumination of 8 lm/ft^2 and they are only about 14 per cent speedier with an illumination of 500 lm/ft^2; whereas, for men about 45 years old, the increase in speed with illumination of 500 lx / ft^2 is nearly 50 per cent.

Bodmann (1962) found that 50 to 60 years old subjects needed illumination in the range 100 to 400 lx to perform as well as younger (20 to 30 year old) subjects working in an illumination of 2 to 5 lx. Weale (1963) demonstrated that visual depreciation is because of factors such as a yellowing of the lens which means that the amount of light reaching the retina of 60 year old person is about one-third of that reaching the retina of a 20 year old person.

Blackwell (1969) found that the lighting requirement of 62 to 66 year olds was seven times more than those of 17 to 29 year old to achieve average performance in contrast discrimination. Blackwell also found that if the degree of contrast necessary to satisfy people in the age group 20 to 25 was taken as unity, then for older people this must be multiplied by a factor, the same being 1.17 for 40 year olds, 1.58 for 50 year olds and 2.66 for 65 year olds.

2.0 CHARACTERISTICS OF THE VISUAL TASK

The size of the work objects in relation to the distance at which they have to be viewed and, the background contrast of the work objects are identified as the primary characteristics of visual task that influence visibility. Weston (1949) classified the visual tasks into three categories based on the viewing distance. Teloramic visual tasks are those where work objects are separated from the eyes by a distance of not less than 6'. Mesoramic refer to those where work objects to be seen are situated less than 6 feet, but not less than 12" from the eyes and Ancoramic refer to those where work objects are viewed from a distance of not more than 10". The visual size of the work object is stated in terms of the angle subtended by the detail of the work object at the eye. The visual tasks were accordingly graded by Weston as large, medium medium-small, small and minute. Contrast in work objects arises from the reflection of light by the work objects which either receive different illuminations or differ in their property of reflecting light. The kind of contrast may be (i) colour contrast, due to differences in the composition of the light reflected (ii) brightness contrast / luminous contrast, due to differences in the amount of light reflected (iii) combined colour and brightness contrast. The investigations carried out to assess the interplay of these characteristics of visual tasks, visual performance and illumination are briefly presented in the ensuing pages.

Lythgoe (1932) found that with illumination constant, visual performance of the subjects varied with the logarithm of the size of the object up to a visual angle of about 4 minutes of arc, but from then on the logarithmic relationship diminished. With the size constant, performance increased with the logarithm of the illumination up to about 50 lm/ft^2 (or foot lamberts) and thereafter increased as the illumination was increased to 1,000 foot lamberts, the increase in performance was relatively low.

Weston (1935) reported that the average worker was able to carry out a job requiring the perception of detail which subtended an angle of 10 minutes of arc at the eye quite efficiently under normal lighting conditions provided the contrast is good. However, there was no appreciable difference in performance. until the size was reduced to 6 minutes of arc.

Luckiesh and Moss (1937) found that raising the illumination level from approximately 10 lx to 1000 lx increased the visual acuity from 100 to 170 per cent and contrast sensitivity up to 450 per cent. At the same time the investigators recorded a decrease in muscular tension (measured from the continuous pressure of a finger on a key) and in the rate of blinking the eyelids. This was interpreted as a reduction in nervous tension as a result of better lighting.

Weston's (1943) study on the effects of contrast on performance using the landolt broken circle technique clearly showed that the performance of the task improved with increasing illumination, but that increase of illumination could not always be a complete compensation for poor contrast often an improvement in contrast, in the work would far outweigh the effect of any reasonable increase of illumination. Nevertheless, an increase in illumination was generally valuable in improving performance and its effect was more marked with poor contrasts than with good contrasts.

Weston (1945) studied the interaction between size and relative luminance difference (r.l.d.) and the interaction of both with luminance, using the identification of orientation of gap on landolt rings as the task by measuring accuracy (the percentage of rings cancelled correctly) and performance (the product of the accuracy and the reciprocal of the time). It was shown that accuracy with size 1 minute could never quite equal to that with sizes 3 and 6 minutes even when r.l.d. was at its maximum at a luminance of 500 fL. With an object of 1 minute of arc an accuracy of 90 per cent could be achieved only when both luminance and r.l.d. were very high. Recognition of gap orientation took slightly longer with size 3 minutes than with size 6 minutes, irrespective of the r.l.d. However, with regard to the size 1 minute, the time taken for recognition greatly increased with decrease in r.l.d., this effect being more pronounced as the luminance was reduced.

Gilbert and Hopkinson (1949) assessed the visual performance of the subjects on a Snellen chart under different illumination levels, using different contrast ratios between the letters and the background. The results indicated that as contrast was increased the subject's ability to read the letters accurately also increased and this effect was particularly marked at the lower levels of overall illumination.

Smith and Rea (1979) experimentally demonstrated that increased lighting would be of value only uptil certain level has been reached. The subjects of the experiment were asked to check a list of 20 numbers for agreement with a comparison list, under different conditions of task luminance (i.e. the light reflected from the paper). It was found that the performance of the subjected increased with luminance upto 10 cd/m^2 but not above this level.

Bauer and Cavonius (1980) and Radl (1980) identified that dark characters on a brighter background (negative contrast) on a visual display led to slightly higher performance and 'preference' ratings than the reverse. This possibly was because the printed page was normally also in negative contrast so that adaptation was maintained when the gaze had to move from the screen to paper and back again.

Colombo and Kirschbaum (1990) found that the print quality of reading and writing tasks affected visual performance of observers. A set of 4760 results obtained with two kinds of tasks, word search and comparison of numerals, showed that the border definition of the marks was an important contributory parameter to high visual performance indices, while the influence of luminance was relatively weaker. At the same time assessment tests indicated that luminance was significant in defining the preference of the observers. The tests were carried out with four levels of adaptation luminance, namely, 15, 50, 110 and 250 cd/m^2.

3.0 CHARACTERISTIC OF THE LIGHT

The level and quality of lighting provided by a given installation can be described by means of essential quantitative and qualitative parameters namely, lighting level, luminance distribution, and glare.

3.1 Lighting level

The amount of light is one of the critical elements in design of any work place as it influences people and may affect their job performance. The level of lighting required in a given situation is specified in terms of illuminance. Three different levels of lighting are established, depending on the type of interior concerned: the minimum for non – working areas, the minimum for working areas and the preferred range for working interiors. Many investigations have been carried out in order to establish these levels and a scale of illuminances ranging from minimum of 20 lx for non – working area through to maximum of 2000 lx has been recommended (Philips Lighting Manual, 1993).

3.1.1 Lighting level and visual performance

Lighting level or illuminance is one of the most critical aspect that influences visibility. Numerous efforts have been made, both in the past and in recent years, to study the influence of varying lighting levels on visual performance and productivity. The relationship between illumination and visual performance of a task (in terms of visual acuity and speed) has been investigated over the years by many workers, both in actual field conditions and under controlled laboratory conditions. The earlier field researches were completely focussed on industrial tasks like weaving, tile pressing, type setting and the like (Elton, 1920; Weston, 1922; Wyatt, 1923; Weston and Taylor, 1926; Weston and Adams, 1927; Weston and Taylor, 1928; Weston and Adams, 1929; Adams, 1935; Lythgoe, 1936 and Weston, 1938). The laboratory methods which each investigator had used were somewhat different. Luckiesh used parallel bars as the test object, each bar occupying one third of the width of a square. The task was to say whether the bars were vertical or horizontal. Weston, on the other hand, used the Landolt ring, a circle with a small gap having any one of the eight common orientations. Blackwell used a disc projected on to at transluscent screen (Murrell, 1965).

Luckiesh (1948) studied under laboratory conditions, that high illumination not only improved visual performance (accuracy and speed of reading), but also reduced the energy expended in attaining a given level of performance. It was observed that the energy expended by the reader continued to decrease rapidly to warrant higher illuminances. Luckiesh's work included such diverse criteria as rate of blinking, and rate of heart-beat, although these were attacked as invalid by subsequent researches.

Weston (1949) found that at normal levels of illumination, the ability to see increased as the logarithm of the illumination, such that from the practical and economic aspect a point was reached at which large increases in illumination produced relatively small increases in efficiency or output. This effect was shown with a test object of one minute of arc that an increase in the illumination from 5 to 10 lm/ft^2 produced an increase of 10 per cent in visual performance, a further increase from 10 to 20 lm/ft^2 produced an additional increase of 10 per cent. However an increase from 20 to 50 lm/ft^2 produced a further increase of only 12 per cent. Kuntz and Sleight (1949) found that individuals with normal visual acuity had no significant increase in acuity above 31.6 f, although the experiment continued to 1,000 fl. The actual increase in performance resulting from the increase in luminance from 31.6 to 1,000 fl was about 7per cent. However, a subject with sub-normal vision reached the same level as the normal subject at about 100 fl. Gilbert and Hopkinson (1949) demostrated that the potential for a particular type of performance (visual acuity) reduced after about 10 lm/ft^2 (107 lx). Subjects with visual deficiencies, however, required much higher illumination levels. On the other hand, Tinker (1949) reported that if visual acuity was taken as a criterion, there was no justification for suggesting more than 40 or 50 lm/ft^2 for adequate illumination, even for tasks that require fine discrimination.

McCormick and Niven (1952), working with a task requiring speed and precision, found a significant decrease in errors when the illumination was increased from 5 to 50 lm/ft^2. When the illumination was further increased to 150 lm/ft^2 there was a slight but non-significant decrease in errors. However, these figures were obtained with objects of high contrast and it can not therefore be assumed that, if objects were very small and contrasts very poor, levels as low as these would be acceptable.

Blackwell (1959) used a simple disc projected on a translucent screen with different sizes, contrasts and time of seeing. The basic experimental task of the subjects was to detect the presence of a circular target located at the center of a field of uniform brightness. The target consisted of a uniform brightness increment presented on the uniform field. The observers were required to prove they could detect the presence of the target by correctly identifying the time interval in a sequence of four during which the target appeared. Extensive data was obtained with field brightness ranging from less than 0.001 to 800 fl, targets subtending visual angles from 0.8 to 64 minutes of arc, and exposure times from 0.001 to 1 second. Each experimental session consisted of 250 target presentations, 50 at each of five target brightness increments to elicit from nearly zero or nearly 100 per cent correct discrimination.

The result of this study showed that the difference between a static laboratory condition and a dynamic moving-eye, field condition is a factor of 15, not in foot candles, but in contrast. Between a circular disc in the field as contrasted with the laboratory, one would need the light necessary for that same sized test object with a contrast $1/15^{th}$ of that of the static laboratory task. Blackwell had also introduced the idea of visual capacity in 'assimilations per second', that is, if the eye is permitted to see the object for one-fifth of a second, it has the capacity of assimilating five items of information per second. In order to relate these experimental results to real life tasks, the visual task evaluator was developed. In this, the contrast of an unknown task was reduced by placing over it a veiling brightness which brought the task to the threshold of vision. When this had been done, a circular disc of four minutes visual angle was reduced to threshold under the same conditions as the unknown task. In this way the task was compared with known parameters of performance for the four minute disc, and the amount of luminance required for the task calculated, when a range of field factors and rates of discrimination were taken into account. Using this technique Blackwell evaluated 56 tasks submitted to him and on the basis of these tasks new foot-candle tables were drawn up by the Iluminating Engineering Society, U.S.A. (1959).

Maitreya (1977) carried out a detailed subjective study on the requirements of supplementary artifical lighting under (i) field and (ii) controlled conditions in office buildings at Central Building Research Institute, Roorkee. The field study was conducted to determine the amount of artificial light in actual use during daytime. It was found that the use of artifical light was mainly observed under conditions when (i) the average luminance of interior surfaces fell below 60 Apostilbs or (ii) the task lighting levels decreased below 100 lx. Laboratory experimentation was carried out with seven male subjects, within the age group 25 to 35 years, who gave the subjective evaluation of the work plane illuminance and interior visual environment. Quantitative assessment was carried out using test papers which included randomly typed letters a, e, o and c and, large number of mis-spelt words. Analysis of the data revealed that the amount of light required for satisfactory performance of an office task varied from 100 to 200 lx. Hence 150 lx task illuminance with modelling vector lying between 1.5 and 2.5 gave an acceptable office interior luminous environment. The average value of 1.2 for the ratio of work plane illuminance at centre to rear of the room laid emphasis on the requirement of uniform lighting on work planes. The acceptability of fluorescent lights (CCT 6800^{o}K) had also been supported. A formula $E_s = 110\text{-}0.88\ E_n$ for $E_n > 30$ lx was suggested for the estimation of the quantum of artificial light required to supplement the available daylight for Indian conditions, where E_s and E_n denoted supplementary illumination and natural illumination respectively.

3.1.2 Lighting level and productivity

Lighting can affect productivity in several ways, controlling our state of wakefulness and moods, thus influencing performance of cerebral tasks. However, productivity may not increase every time "good" lighting is installed in a building. Lighting is only one element an architect considers when designing a building, and it may not be the most crucial one. Other factors like labour relations or the type of task at hand also affect productivity. Still, lighting is undervalued by those unaware of this research because its relationship to productivity is complex and statistical in nature. (Rea, 1992).

The experiments conducted at Western Electric's Hawthorne Works in Chicago were one of the earliest attempts to gauge the correlation between lighting and worker productivity. In the first three of seven experiments, researchers tried to determine how changing illumination would change work rates. Results from these tests convinced researchers to continue their work. On the basis of these seven studies, the Hawthorne effect – an unconscious attempt by the test subjects to please the experimenter or react positively to management's perceived interest in their working conditions – was identified. Though these experiments did more for organisational behaviour theory than for lighting, but the industry began to analyze what it meant to have quality lighting in the work place.

Numerous studies (Hopkinson and Collins, 1970; IERI, 1975; Ross and Baruzzini, 1975; Hughes and McNellis, 1978 and Barnaby, 1980) examined the relationship between the amount of illumination and productivity. Most had shown some increase in productivity as illumination increases, but the amount of the increase was task - dependent. It was not clear, however, how much of the change was attributable to improved seeing and how much to motivational factors. Typically, the increase in productivity was larger when the tasks were visually very demanding or when the workers were over 45 years of age. Increase in illumination had no effect, or only a small one, on productivity for younger workers and less visually demanding tasks.

Grandjean (1988) reported on the results of 15 industrial studies carried out by McCormick and Sanders. An increase in output, ranging from 4 to 35 per cent, was shown with increasing levels of illumination. The original level had been very low, however, less than 100 lx. McCormick had reservations that the increase in output could be, because of the existence of other, uncontrollable factors that were always present in such situations. Yet, in spite of this valid criticism, there was no doubt that the increase was partly due to the previous inadequate lighting.

Grandjean (1988) further reported that a survey in an American cotton-spinning factory showed a stepwise improvement in productivity when the general illumination level was increased. When the illumination was raised from 170 to 340 lx, the production rose by about 5 per cent, while simultaneously the amount of rejected product was sharply reduced. As a result, the total costs fell by 24.5 per cent. This result encouraged the management to increase the illumination still further up to 750 lx, whereupon production rose to 10.5 per cent above the original level, and the reduction in wastage brought costs down by almost 40 per cent. Similar results were obtained in England, France, Germany and other countries, showing an increase in productivity, reduction in rejected products and fewer accidents with increase in levels of illumination.

Rea (1992) indicated that the level of vigilance and wakefulness in the early morning hours was very low, but could be substantially improved using higher lighting levels (i.e., 2500 lx) than those currently used (typically, 300 lx). Baron, Rea and Daniels, 1992 identified lighting as an environmental cue for inducing "positive affect". People with positive affect were more likely to help others, volunteer for more work, take greater risks, and "see the big picture". Such attributes could undoubtedly affect productivity.

3.2 Luminance distribution

The luminance (or the brightness) distribution within the field of view is an extremely important lighting parameter. For a given lighting level, differences will be due to differences in surface reflectance. Although the illuminance may be appropriate for the visual task, it will not necessarily give an acceptable luminance balance in the interior as a whole. This balance, or lack of it, will depend on the room-surface reflectances. Lighting can at best help to make the most of a poor situation in this respect, but the result will always be visually unsatisfactory.

Lythgoe (1932) studied the effect on visual acuity of varying the brightness of the immediate surrounding to the task. He found that the acuity was at its optimum when the surround brightness was equal to or slightly less than the task brightness. The fall in acuity was sharpest when the ratio was 1:10. When the surround was three times brighter than the task, the loss of acuity was equivalent to reducing the illumination by 60 per cent. Lythgoe also studied pupil size in his research and he pointed out that the surround brightness will determine the level of adaptation of the eye as revealed by pupil size.

Experimental evidence of the effect of the luminance ratio on a task was obtained by Luckiesh and Moss (1932). The subjects were made to set one pointer against another by means of a control. The two pointers were black on a white background and the surroundings of the task were either illuminated to the same extent as the background or were not illuminated at all. Performance with the dark surroundings was approximately 10 per cent lower than that with the light surroundings.

The effects of brightness ratio was assessed in a study by Biesele (1950). The task brightness was maintained constant at 20 fl and subjects were required to mark landolt's rings under task/surround brightness ratios between 1:0.05 and 1:10. An optimum performance (or acuity) was observed when the task was lighter than surround up to a brightness ratio of about 1:0.3. From these results it was concluded that for maximum visual comfort and efficiency, the task should be of high reflectance and the immediate surrounding should be rather darker than the task, and the more general surroundings should, ideally, be rather darker still. The luminance of the task should not differ by a ratio of more than three to one from that of the immediate surroundings (I.E.S. London, 1961).

The effect of distribution of brightness in the visual field, with regard to specular reflections (reflection from gloss) from various areas within a visual task, to alter the contrast of the details was also been explored. Work by Finch (1958) showed that the specular reflection and hence the contrast varied with the position of the light source and orientation of the task. Measurements of this sort emphasised the importance of the paper surface and the indentation of the writing or printing.

Extensive field measurements were carried out by Chorlton and Davidson (1958) in a room 23 x 30 x 10 feet under 3 rows of 4-lamp direct-indirect luminaires. Three stations were selected for experimental purpose. First 10 feet from the rear wall on a desk under the center row, second 15 feet from the rear wall on a desk under the right hand row, and third 15 feet from the rear wall on a desk half-way between the center and right-hand rows of units. The five tasks studied were light weight pencil writing on mat paper, printing on glossy and non-glossy paper, printing on a mat test card, and heavy pencil work on mat paper. The loss of contrast for lightweight pencil lines on mat paper at each station was measured by a Cottrell contrast threshold meter and found to be 15, 17 and 17 per cent respectively. Comparatively good printing on semi-glossy stock showed losses of 10, 14 and 15 per cent, and the same printing on mat stock gave values of 4, 5 and 11 per cent. Heavy weight pencil on mat paper showed losses of 19, 21 and 26 per cent.

Blackwell (1958) studied the relationship between contrast and the brightness that was necessary to compensate for lower contrasts. Measurement of required quantity of illumination for a specific level of visual performance were determined under no - glare conditions. It was concluded that when glare conditions or specular reflections were encountered efforts should be made to provide the equivalent no-glare visibility. This could be done by increasing the illumination to compensate for the loss of contrast.

Grandjean (1988) reported the observations of Guth, that there was a decrease in contrast sensitivity in the subjects and an increase in the eye blinking rate when the centre area of the visual field was five times brighter or darker than the adjacent area. According to these experiments relative contrast ratios of 1:5 in the middle of the visual field significantly impaired the efficiency of the eye as well as visual comfort. If the adjacent areas were brighter than the centre area the disturbances seemed to be more strongly felt than vice versa.

3.3 Glare

Glare is the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause discomfort, reduced visibility, or both. Glare can take either of two forms, which sometimes occur separately but are often experienced simultaneously. The first is known as disability glare, which results in reduced visual performance and visibility. The second is discomfort glare, which although producing a feeling of discomfort, does not necessarily impair visibility. Glare, whatever the type, can be direct or reflected. Direct glare can be caused by, a bright luminaire appearing in the field of view of an observer, Reflected glare will occur if the observer sees the reflection of such a source in a glossy surface (Phillips Lighting Manual, 1993). In interior lighting practice, discomfort glare is likely to be more of a problem than disability glare. The feeling of discomfort tends to increase with the passage of time, and contributes to stress and fatigue. The discomfort produced by a glare source appears to have a different physiological origin than does disability glare. Control of direct discomfort glare from lamps and luminaires involves controlling the luminance of these in the direction of the observer's eyes. The degree of luminance control called for will differ from one type of task or activity to another. For this reason, the CIE has classified tasks and activities into five groups according to the degree of luminance control needed, which are referred to as quality classes, namely, A, B, C, D and E. In the scale of glare rating, a quality class is recommended for very exacting visual tasks, through to E quality class of glare which is acceptable for tasks of low visual demand.

Stiles (1929) and Crawford and Stiles (1937) illustrated the fact that the light from the glare source is scattered in the fluids of the eyes, which results in reduction in contrast and hence visibility. In their experiment, the glaring light source was presented on the blind spot of the retina. Although the light source itself was invisible, its veiling effect was still present.

Hopkinson (1956) demonstrated a link between the level of discomfort and the activity of the eye musculature which controls the iris. This relationship, however, was not perfect and the investigator concluded that discomfort sensations were due only in part to the conflict which arose between the requirements for pupil control between the areas of the retina that were stimulated by the glaring source, and those that received lower levels of illumination.

High mast flood lighting at outdoor workplaces has economic advantages but suffers from short comings such as glare. Carlsson, Knave and Wibom (1983) found that highly luminous luminaires occupied a fairly central position in the visual field of the workers of a timber terminal and since a great deal of the work had to be done with the gaze directed upward, the outdoor workers complained of a glare problem in their work. Moreover, in the experimental study evidence was found of reduced performance due to effects on visual acuity caused by glare from the high mast lighting.

4.0 VISUAL COMFORT

The utilitarian goal of a lighting system is to provide for optimal performance of a given task. The preliminary determination of the quantity of illumination required for objects which have to be seen with foveal vision can be based upon the relationship between illumination and performance. However, it cannot be emphasized too much as this is only a starting point. The final recommendation of quantity of illumination must take into consideration other factors such as the avoidance of fatigue, physiological and psychological costs not reflected in the evaluation of performance, the possible impairment of vision and health, economics, and the cultural or emotional effects of light (IES, 1959). A pleasant visual environment can play an important role in alleviating psychological stress and fatigue.

The relationship between overall illumination and subjective factors such as comfort was studied by Saunders (1969). The subjects were allowed to adopt to a windowless room lit only by ceiling lamps and were then asked to read from a book. Subsequent ratings of the illumination quality to which they had been exposed showed that with increasing illuminance levels, subjects judged the lighting to increase in quality until, at about 800 lx. Thereafter no increase in the ratings of the subjects on illumination quality was observed with further increase in illuminance levels.

Shahnavaz (1982) stressed upon the need to consider the preference of the workers for environmental conditions of the work place, rather than merely following the general recommendations. Results of his study on 28 VDU (Visual Display Unit) Operators in a Swedish telephone information centre revealed that operators had preferred, in general, much lower luminance and work place illuminance than the recommended values ; both for the day shifts and night shifts. The preferred mean illumination levels on the telephone catalogue were 322 lx during the day and 241 lx for night shifts with similar levels on the desk and on the key board. The preference for such low values by the operators were mainly based on the argument that it would create a more acceptable working environment and prevent reflection from the screen. The study also revealed large interindividual differences in screen and work place lighting adjustment.

Grandjean (1988) cited the works of Benz and his associates, Heiden, and Brauninger. He reported that Benz and his associates carried out a study in Germany which revealed that 40 per cent of the VDT (visual display terminal) operators preferred levels between 200 and 400 lx, whereas 45 per cent preferred levels between 400 and 600 lx. During a study of 38 CAD (computer-aided design) work-stations van der Heiden observed that a number of lights had been switched off, reducing the mean illumination levels to around 120 lx. Brauninger revealed significant relationships between the photometric characteristics of VDTs and symptoms of visual discomfort. Screen flicker, excessive luminance contrast ratio between screen and environment, reflected glare on the screen and poor readability were related to an increased incidence of visual complaints. These findings led to the assumption that sharpness, luminance contrasts, stability, character flicker, screen reflections and the geometric design of characters might decrease the legibility and produce occasional visual fatigue.

Sato, Inui and Nakaura (1989) examined the relationship between a pleasant atmosphere and the physical factors constituting the visual environment of the control room. A series of experiments were carried out using fifteenth-scale model of control rooms. The important physical factors chosen as parameters were the illuminating system, reflectance of louvres, illuminance level, height of ceiling, colour of control panels, presence of windows, presence of potted plants and so on. Sementic differential rating data were analysed by factor analysis. The two psychological factors 'spaciousness' and 'friendliness', were extracted, and the relationship between these factors and the physical factors was clarified.

Shepherd, Julian and Purcell (1989) established experimentally that gloom is a commonly held experience. This was determined by making groups of observers appraise a room under different lighting conditions. In the second and third stages of the study in 1990, the investigators examined the extent to which the experience of gloom depended upon intensity and distribution of light and the range of surface reflectances in an interior.

The human physiological and psychological response to variable lighting was experimentally studied by Russell, Hartleb and Hartleb (1990). The results from the experiment showed that the time of the day did not influence the preferred illuminance for either a reading task or a listening task. However, there was evidence that higher illuminance were preferred for visual than for auditory tasks, that preadaptation lighting levels influence the preferred illuminance for a task, that the sex of the subject affected the preferred illuminance, and that subjects who normally go to sleep before midnight prefer lower illuminances than those who stay up later.

Boyce and Cuttle (1990), through an experimental work, found that illuminance was a major factor determining the impression given by the lighting. Increasing the illuminance made the lighting of the room appear more pleasant, more comfortable, clearer, more stimulating, brighter, more colourful, more natural, more friendly, more warm, more uniform, less hazy, less oppressive, less dim, and less hostile. The correlated colour temperature of the lamps used had virtually no effect on the observer's impression of the lighting of the room. The other major factor that influenced the impression of the lighting of the room was the presence of natural colour. Introducing natural colours in the form of fruits and flowers, enhanced the positive impressions created by lighting, particularly at higher illuminances.

5.0 PHOTOBIOLOGICAL EFFECTS OF LIGHT

One of the recent aspect of research in lighting is the photobiological effects of lighting : the non visual effects of light exposure on human physiology. Laboratory experimentations clearly demonstrate the photobiological effects of light and indicate the fact that lighting for photobiological purposes could have an impact on the lives of many people. Soon, the lighting designers would be faced with a basic question. "Is the fundamental objective of lighting to provide appropriate level of visibility without discomfort, or should we consider the photobiological effects of lighting as equally, and sometimes more, important ?". Researchers believe that one of the factor that contribute to early morning awakening and reduced daytime alertness is a reduction in exposure to light.

Boyce (1997) reported that using core body temperature as a steady-state condition, researchers of Harvard Medical school found that the phase shift in core body temperature following exposure to a light pulse at a given time is directly proportional to the cube root of the illuminance at the eye. He thus concluded that light could be effectively used to shift the phase of circadian rhythms and enable the worker's wake period (i.e. the alertness period) to adjust quickly to the night time. These phase shifts could make night-shift work more bearable for workers and reduce accidents as workers drive home in the morning. Sanford (1997) stated that a high dose of light in the morning can lead to health benefits amongst the elderly. It aids to alleviate symptoms like erratic sleep pattern, special craving for sweets during summer, experiencing blue moon and feeling draggy during the day.

Satlin, et.al., (1992) found that exposure to bright light during the day could make the rest-activity cycles of some people with Alzheimer's disease more regular. He thus suggested that providing higher illuminances in places where Alzheimer's patients are cared for, might benefit the caregivers who often have their sleep interrupted, by making ministering to these patients easier. Flynn (as quoted by Rea, 1992) showed that lighting levels as well as lighting geometry and colour had an effect on people's perceptions of a space. He reasoned that the perception of a lighted space might affect a person's ability to perform cerebral tasks as well as widget – production tasks. Boyce (1997) reported the work of Badia who found that the immediate effects of light exposure were change in EEG patterns and increase in core body temperature, both indicative of increased alertness. Boyce also cited Campbell and Dawson and French, et.al., who demonstrated that exposure to bright light led to improvements in complex cognitive tasks requiring logical reasoning and short-term memory.

The field measurements reported by Coel, et.al., (cited by Boyce, 1997) indicated that many older people do not stay outside for long periods and, because their homes are poorly lit, they have little exposure to high illuminances. This implied that many of the elderly could benefit from exposure to higher illuminances in the evening, which would delay the phase of the sleep / wake circadian rhythm and might also increase the amplitude of the sleep / wake circadian rhythm, thereby reducing the tendency to sleep during the day.

6.0 DAYLIGHTING

Daylight in buildings is becoming an increasingly popular choice in lighting design both because, with appropriate design, it offers low energy solutions, and for the (generally) pleasant environment it creates. Natural daylight penetrating into a room establishes contact with the world outside, giving a view of the surroundings and indicating the time of day and the state of the weather. Sunlight can produce positive emotional and aesthetic effects, provide a strong directional light for difficult visual tasks, and provide a close link with the outdoors if it is carefully controlled to prevent the negative effects. The windows in an interior space, besides admitting light, fulfill essential visual functions by allowing a view of the outside, and thus have a psychological importance to the occupants of a space. People like visual contact with the outside world. It is also believed that windows, especially in a domestic environment, have an influence on health, although this has not been scientifically validated. Mant and Muir Gray (1986) asserted that windows have an important effect on the way a space is perceived. To provide this for occupants in a deep plan office at least 25 per cent of the window wall needs to be glazed (BRE Digest 226, 1979)

Cuttle (1983) found that workers in office buildings in both New Zealand and England revealed that windows were important in the workplace and that the majority preferred to work by daylight, largely because they believed that to work by artificial light caused both short-term discomfort and long-term deleterious effects. It was also found that windows were considered more desirable as their size increased.

Boyce (1981) presented a valuable review of such studies which have demonstrated mixed reactions to windowless rooms, often depending on the room function and the number of other occupants that it contains. He quoted the work of Ruys (1970) who surveyed occupants in five different buildings in America, each containing a number of windowless offices. Whereas there appeared to be few complaints about the level of artificial lighting provided, nearly 90 per cent of the occupants expressed dissatisfaction with the lack of windows. Those office workers who often had to work alone complained that a lack of windows meant a lack of daylight, poor ventilation and an inability to know about the weather or to have a view. It also gave an impression of being cooped up and led to feelings of depression and tension. On the other hand, studies performed in factories, which are often windowless but in which space is usually large and contains a number of other people, suggested few complaints (Pritchard, 1964). Boyce also reported similar findings from studies investigating the effects of windowless classrooms on schoolchildren. Indeed, in some cases the children performed better in rooms without windows.

Based on such contradictory data such Boyce concluded that it is not the lack of windows per se which is a cause for discontent but the social setting of the environment and the size of the windowless space. The environments in which there was adequate scope for social interaction (factories and schools), with larger rooms, the complaints were rare. In smaller office-type environments, however, with reduced chances for social interaction, complaints were heard. Furthermore, Boyce argued that equality of circumstances is important in such cases. He illustrated that Sommer (1974) found that the dislike of a windowless environment in the underground offices which he studied was amplified by the fact that the executives had offices above ground with windows overlooking fine views.

7.0 RESEARCHES RELATED TO RESIDENTIAL LIGHTING

The probative attempt of the investigator revealed that a little research has so far been devoted in India and abroad with regard to residential lighting. The few available research studies are described in this part of the review.

Chandapilla (1964) attempted to evaluate the existing lighting system in the drawing rooms of 100 selected families. A wide gap between the standard levels of illuminance and existing levels was observed. It was found that only 11 per cent of the drawing rooms had the required levels of illuminance for reading of 100 lx. The study revealed the ignorance of the homemakers regarding the role of factors, like, colour of room surfaces and cleanliness of lamps in good lighting. The investigator concluded that failure in cleaning of lamps and use of dark or bright coloured upholstery and furnishing were the primary factors that contributed to poor lighting levels.

A field survey conducted by Abraham (1970) pertaining to the lighting condition of study area in the university hostels and homes of the students revealed that the existing lighting conditions were far from adequate in quality and quantity. It was found that only 5 per cent of the sample had an illuminance of more than 10 f.c. at the study area. Inadequecies of the light sources, low lumen output and inappropriate use of shade were identified as factors contributing to low levels of illuminance and poor distribution of light. In general it was observed that the study areas in residences had better lighting conditions as compared to that in the hostels, since a high proportion of the former cases had a combination of general and local lighting. Also, the knowledge level of students in relation to lighting and then ability to apply principles were found unsatisfactory.

Desai (1977) carried out a survey of 80 residential dwellings to assess the existing condition of artificial lighting in living rooms and kitchens. It was found that fluorescent lamp was the most popular light source in living rooms and kitchens and the light sources were observed to be free from dust and dirt in two-third of the living rooms and one-half of the kitchens. The lumen output of light sources ranged between 2401 to 4400 lumens and 400 to 2400 lumens in the living room and kitchen respectively. The average watt power provided per square foot area of living room and kitchen was found to be much below the recommended values of 2.4 and 4.8 watts/sq.ft. for living room and kitchen respectively. Further it was found that illuminances at specific task areas in living room and kitchen were found to be far below the values recommended by the Illuminating Engineering Society and Indian Standard Institute. The average illuminance for cooking area, preparation area and dishwashing area in the kitchen were observed to be as low as 4 fc, 4 fc and 3 fc in the rented houses; and 12 fc, 11 fc and 12 fc in the owned houses, respectively.

Saxena, Kumar and Pal (1980) explored the existing practice of lighting design and the prevailing levels of illuminance in residential buildings in a study conducted on night time artificial lighting. It was observed that the lighting in homes was generally unsatisfactory due to inadequate wattage of lamps used, inappropriate location of light points and poor maintenance of lamps and reflectors. None of the kitchens had the ISI recommended illuminance of 200 lx on the cooking platforms. A 60 watt incandescent lamp was found to be the most commonly used lamp in kitchen. On the basis of laboratory measurements, the investigators recommended that in view of desirable economy and energy conservation, the lumen method of design as given in the Part I of the ISI code was neither practicable nor advisable for residential buildings. A rational design approach for homelighting should be that of spot lighting of specific areas in a room where a particular visual task is most likely to be performed. The general illumination of a room should however, be such as to satisfy the brightness ratio of 1:10 of the general surrounds and the task.

A lighting survey covering approximately 140 domestic dwelling of elderly citizens in Australia was carried out by Merz (1982). It was found that rather than using increased illumination, elderly frequently use less, through the mistaken belief that they are making considerable cost savings. There are also entrenched misconceptions such as "too much light will harm the eyes", "sitting too close to the TV will damage the eyes", "it is important to have a (glaring) table lamp placed on the top of the TV set". The night time and day time illuminance at working areas in kitchen were observed to be 100 lx and 150 lx respectively. Comparisons were made against illuminance recommendations of 200 lx and 300 lx the Australian and that of New Zealand respectively. Similar observations were made in the homes of the elderly examined at the Wellington Hospital Low Vision Clinic in New Zealand. It was found that illumination levels rarely meet the minimum standards set down by Standards Association of New Zealand in 1984.

A lighting survey of 101 homes was carried out by Simpson, Tarrant and FinstP (1983) to determine the levels of illuminance in the kitchens, stairs and halls and at tasks like sewing, casual reading and prolonged reading or desk reading. The illuminance levels were found to be inadequate in majority of the cases. The median values for illuminance at cooking, food preparation and sink area ranged between 70 lx to 80 lx; median values for bottom stair and hall illuminance was

20 lx and 30 lx respectively, while the median for task illuminance for both casual and prolonged reading was 70 lx. The investigator reported that poor provision of fixed lighting was an attributory factor to low illuminances.

McGuiness, Boyce and Harker (1983) studied the effects of illuminance on tasks performed in domestic kitchens. A reported measures experimental design was adopted and 32 subjects with age ranging from 20 to 64 years were required to perform four selected tasks at four varying levels of illuminance. Analysis of variance showed that no significant differences were observed in the mean performance time for searching information in a recipe book, reading and interpretation of weighting scale and slicing cucumber. However significant differences were observed in the mean performance time with regard to examining stains on dinner forks. The Friedman's Test revealed significant increase in rated satisfaction and decrease in perceived difficulty and effort with increase in illuminance. The McNemar Test showed an significant increase in the various forms of modified behaviour with decreases in illuminance.

The existing daytime and nighttime illuminances in the kitchens were assessed by Luthra (1987). The findings revealed that majority of the kitchens had window area more than 10 per cent of the floor area and the amount of day light was observed to be adequate. However, the levels of illuminance (shadowed and unshadowed) provided by artificial source of light, which in majority of the cases was a fluorescent lamp, was assessed as inadequate. The investigator further reported that the time taken to perform kitchen activities like, cleaning of rice, reading a recipe, washing mugs and roasting semolina, in an experimental set up showed a decrease in trend as the illumination levels were increased.

Thakkar (1989) reported that poor conditions of artificial as well as natural lighting were observed at the study area in the selected residences and the hostels. The assessment of artificial lighting was made in terms of illuminance, glare, contrast and shadow. The study further, revealed that illuminance required for reading was approximately 600 lx which could be well met by installing a task light at the study area.

Carter, Sexton and Miller (1989) evaluated the results obtained through different techniques of the field measurement recommended by the Chartered Institution of Building Services Engineers (CIBSE), Illuminating Engineering Society (IES) and DIN standard. They reported the results of a series of comparative field measurements of the various lighting codes and modifications were suggested to the CIBSE method.

In the light of the literature surveyed, it was found that the researches in the past were primarily focused on the quantitative aspects of lighting, and were mainly directed towards assessment of visual performance of the subjects. The investigations carried out in the recent years constitute a wholistic approach to lighting whereby the qualitative aspects of light is considered as integral part as well. However, the researches both in the past as well as in the recent years have been concentrated on industrial/ commercial/ hospital/ theatre lighting while the lighting in residential units has drawn minimum attention.