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Harnessing Natural Light For Energy Efficiency in Buildings.

Sashikala Ranasinghe and Ranjith Perera

This paper is written within the premise that lighting accounts for a sizeable portion of the total energy requirements of Sri Lanka. It is also noted that efficiently planned usage of daylight for building interiors could result in considerable savings in energy and thereby lead to energy efficiency. The intention of this article is to highlight few key design criteria which must be considered by architects in harnessing natural light to make the buildings they create energy efficient. Although these criteria are commonly known, lack of understanding and application are amply demonstrated in contemporary Sri Lankan buildings.

1.0 NATURAL LIGHTING

When dealing with day lighting, there are certain universally applicable facts pertaining to natural lighting of building interiors, which would be useful in the local context as well.

They are;

1. In the natural lighting of building interiors, daylight and sunlight are treated separately and as such design considerations would be different.
2. Daylight is received either directly from the sky vault, opposite the window or as reflected light from an opposing façade or intervening ground, the brightness of which is a relevant factor.
3. Prediction of sunlight within an interior is purely a geometrical exercise related to sun path, orientation of the window, dimensions of the window and external obstructions.
4. Designing sun shading devices and sunlight reflecting surfaces are based on the above geometrical procedure.
5. The daylight factor concept of assessing the minimum size of openings required to provide the desired level of illuminance within an interior is based on the 'design illuminance' unique to each country .
6. Glare, an undesirable quality of light is due to excessive brightness in the field of vision. Shading devices, low transmission glass and proper orientation are some methods adopted to reduce the effect.
7. Solar heat gain within an interior is dependent on window design, orientation, building mass etc. Direct sunlight on glazing contributes to excessive heat gain.
8. The nature of orientation of a window is one important factor which determines the quality, quantity and the character of lighting within a space.

These facts reveal that orientation of windows, size of windows, light reflecting surfaces and light controlling devices are the most important criteria to be considered in providing good quality lighting to interiors by way of natural lighting. Yet it is seen that aesthetic considerations very often override functional considerations in window design. Over-emphasis on aesthetic considerations has not only resulted in undesirable lighting qualities in interiors but also poor efficiency in the usage of energy. Therefore this article attempts to remind the architects on the facts pertaining to the key criteria noted above and our next article attempts to demonstrate the energy efficiency which can be achieved by giving due consideration to those design criteria.

2.0 ORIENTATION

Whilst satisfying the requirements pertaining to the orientation of the building as a whole such as access, desired appearance from the principal direction of view, nature of the built environment in the immediate vicinity, satisfaction of statutory requirements and wind direction, the orientation of the principal facades that would contain the windows that provide natural light to the interior should receive priority attention.

The quantity and quality of natural light within an interior would be determined by the sizes, shapes and other critical features of openings that are positioned in a manner to effectively receive light from the sky and their reflected components.

During most parts of a working day from about 8.00 a.m. to 5.00 p.m, the sun would be visible from one half of the year in the northern sky and for the other half, in the southern sky. Thus orientation of windows to the North and South would be the most efficient way to receive daylight. However, it must be remembered that appropriately designed windows should be provided to reduce the adverse effects of direct sunlight and the view of the sun.

The orientation of the windows in relation to external obstructions such as buildings and other structures in the vicinity is also an important consideration. There are three important aspects to this situation.

The first aspect is that any form of external obstruction could considerably reduce the contribution from sky luminance and also from direct sunlight, depending on the nature and magnitude of such obstruction. Secondly such obstructions could however be utilized advantageously as reflecting surfaces to bring light from opposing sky dome and the sun (see Fig.1).

Depending on the size, reflectivity and orientation of such surfaces, they could act as effective secondary sources of light. Therefore in a heavily built- up situation that cannot provide light from the sky, windows should be oriented towards the façade of a nearby building.

Thirdly the intervening ground between the window façade under consideration and the adjacent obstruction could be an effective plane for ground reflected daylight and sunlight (see Fig.1). In this regard the ratio between the width of intervening ground and the height of obstruction is the critical factor, and this ratio should be such that the 16N and 30S sunlight is least obstructed. An experimental survey carried out in conjunction with windows shows that ground reflected light had a major contribution towards strong interior illuminance (Ranasinghe, 1996). Therefore, providing adequate spacing between buildings or making use of spaces such as streets and paved walkways or open areas should be given due consideration for obtaining ground reflected light.

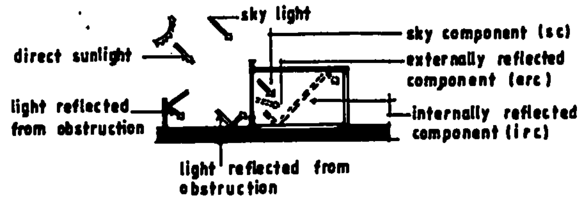


Fig. 01
Source: Concepts of Architectural Lightng. David, E.M

3.0 OPENINGS

Openings or windows are the basic and critical elements for the presence of natural light within a building. Together with the provision of visual communication with the outside and mental/ visual comforts of the occupants, their size, shape, position, orientation etc. are the determining factors of quality and quantity of light that is admitted to the interior.

Therefore, a comprehensive analysis of the relationship between window types, sizes, shapes, orientation, distribution of light and transmission qualities are important to be considered in a study on daylighting.

3.1 WINDOW SIZES, SHAPES & LIGHT DISTRIBUTION PATTERNS

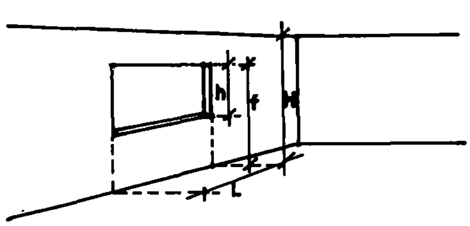
a. Vertical Openings:

The conventional openings on vertical facades, referred as vertical windows transmit light into the space on a near horizontal plane to light up the vertical facades that provide the required brightness to the interior.

The efficiency of the windows on vertical facades is determined by the optimum depth at which the required level of illuminance can be achieved. It is measured as the daylight factor (DF). The uniformity of spread within the space is determined by the rate at which the Daylight Factor would falloff towards the rear. The lateral spread of illuminance is indicated by a Daylight Factor contour diagram. As stated by Robins (1986:70), for side lighting systems, proportional relationships that describe the penetration of daylight into the space are;

Aperture Height (h)/Jamb Height (f) ratio H=h/f and, Ceiling Height (H)/Aperture Height (h) ratio V = H/h.

The proportional relationship that describe the spread of daylight is given by the ratio- of; Aperture Length (L) / Aperture Height (h) M = l/h.

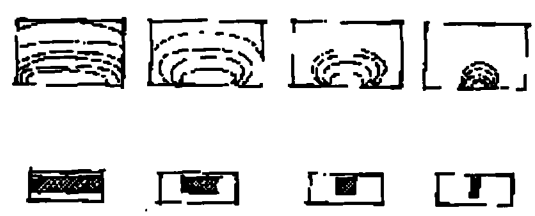


kye dimensions for determining $\overline{H}$. $\overline{V}$. $\overline{M}$. ratios

Fig 2

Key Dimensioning for Determining H, V, M ratios

The $\overline{H}$ ratio is the most important ratio to be considered in designing side lighting. Varying M should change both spread and penetration pattern of daylight entering through the aperture. The lateral spread of daylight into the space will begin to approach the maximum distribution characteristics when M = 4:1. This means that the penetration of daylight into the space cannot be substantially increased once the aperture has reached about 4:1 length to height ratio (see fig.3). In other words it means that excessive use of glass does not bring additional light into an interior space. However, excessive use of glass contribute to heat gain.



spread of daylight factor curves for windows when $\overline{H}$ = 1.5:1 $\overline{V}$ = 1.1 and $\overline{H}$ is varied as follows

a) $\overline{H}$ = 4:1

b) $\overline{H}$ = 2:1

c) $\overline{H}$ = 1:1

d) $\overline{H}$ = 0.5:1

Fig 3

Source: daylighting, Design and Analysis. Robbins, C.L

Experimental work at the Building Research Station in UK, on preferred window shape in relation to external view indicates that user satisfaction falls off steeply if less than 20per cent of the wall is having glazed areas. Satisfaction rises to near maximum with glazed areas that occupy between 20 per cent to 30 per cent of the wall. This indicates that excessive use of glass on external walls is undesirable not only for light condition and thermal comfort but also for visual comfort. Thus the above ratio is a very important factor to be considered in designing windows to receive desirable amount of day light.

b. Horizontal Openings:

Openings on horizontal planes, generally referred to as sky lights are very effective entry points for natural light. This concept can be used to enhance the depth of penetration of side lighting. However, they are often used in cases where the design or lighting criteria make side lighting inappropriate.

The decision to use top lighting rather than side lighting is based upon design criteria other than the lighting needs of the building. For example, in a building where perimeter surfaces need to be used as task or work surfaces, top lighting is a logical choice. Similarly, in a single storey building that is very deep, top lighting alone or coupled with side lighting may be more appropriate than side lighting alone.

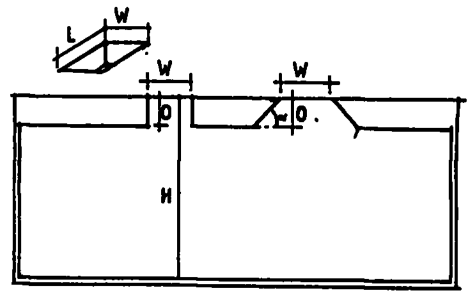
As emphasized by Robbins (1986:89), top lighting concepts are often the easiest day lighting concepts to integrate with artificial lighting, since the light enters the space from ceiling of the room in most cases. The primary positive aspect is the evenness of light distribution throughout the space (with primary lighting zones located directly under the aperture and secondary and tertiary lighting zones located in the perimeter). The negative aspects of top lighting is that it is limited to single storey or low-rise buildings and the view of bright sky may create the problem of glare. However, these problems could be rectified by good window design.

Two of the aperture proportions used to describe the side lighting concepts are also used to describe top lighting concepts, i.e.,

Ceiling Height (H)/Aperture Height (O) ratio H = H/O and,
Aperture Length (l)/Aperture Width (w) ratio M = l/w.

Horizontal apertures can also be described in terms of the ratio of aperture height above the floor (H) to the width of the aperture (w) given by N.

N = H/W



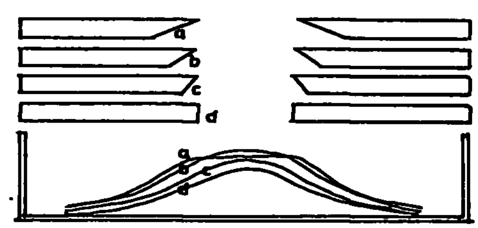
Variables used to describe horizontal apertures

Fig 4

In the case of light wells, through which daylight must penetrate can have a significant impact upon distribution and quantity. The proportional relationship between top to bottom height of the well (o) and the height to the bottom of the aperture above the floor (H) is called the O ratio is when the slope of well is 90o.

O =H/o.

The slope of well and the well reflectivity also affects light distribution. Varying the slope of the well from 90^0, 60^0, 45^0, and 30^0 would increase the spread of light. Increased reflectivity of slope would improve the quantity and quality of lighting (see Fig.5). However, horizontal windows very often make excessive light and heat gain in interiors. Thus light controlling devices are needed to regulate the light intake.



Variation in illumination with horizontal aperture when $\overline{N}$ = 2:1 $\overline{O}$ = 4:1 $\overline{M}$ = ∞:1 and when well slope is varied as a) 30°, b) 45° c) 60°, d) 90°

Fig 5

Daylighting Design and Analysis, Robbins, C.l

The use of light controls on horizontal apertures should take into account the height of light well and its slopes and the sun path. Care must be taken so that the efficiency of the exercise is not reduced by these devices. The angle of glazing on the aperture (flat, domed or angled) will not be of much significance compared to the dimensional characteristics of the aperture of the light well. Light wells can also be used to distribute daylight over several floors of a multi storey building. The maximum number of floors that can be day-lit is usually not a function of daylight distribution but of building requirements.

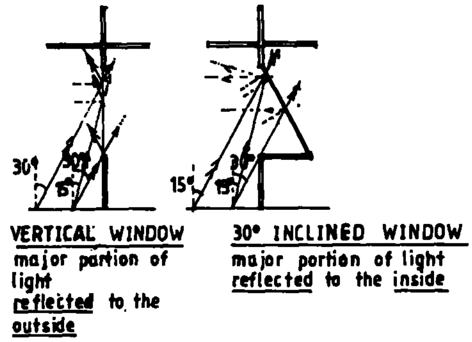


Fig 6

4.0 GLAZING MATERILAS AND THEIR PROPERTIES

The transmittance properties of glazing materials used in windows of all types depend on their refractive indices and the angle of incidence of light, that would appreciably affect the illuminance level within an interior.

The degree of transmittance of glazing material is one of the important factors which determines the efficiency of the utilization of daylight. The higher the transmittance factor, the higher would be the efficiency or vice-versa.

The normal clear glass, which has a refractive index of 1.5 would have a transmittance factor of approximately 94 per cent when the light enters perpendicular to the plane. If the angle of incidence is varied from this perpendicular line, the transmittance factor would start decreasing from about 40^0. The decreasing rate would change rapidly after 60^0. Daylight falling at angles of incidence over 40^0 would be partly reflected and partly transmitted resulting under-utilization of available light or in other words inefficiency.

Therefore, by sloping the glazing to an appropriate angle so as to make the angle of incidence less than 40^0, maximum transmittance of light can be obtained (see Fig.6)

More over, the brightness of the sky seen through the window can be reduced by sloping glazing surfaces. This arrangement could be highly advantageous in locations where there is a strong contribution from external sources as well as disturbances from the bright surfaces in the field of vision.

However, body tinted glazing too could help in the reduction of glare due to external brightness from the sky. But the nature of its tint could change the colour of daylight that is transmitted through it. This is undesirable specially in situations where colour rendering quality of natural light is important.

The 'body tinted' glasses can help in arresting the flow of ultra-violet radiation and prevent the occurrence of 'green-house' effect. However, it has been found that the transmittance properties of all such glazing are much poorer than clear glass.

In the situation of mirrored glass, it is true that a fair proportion of radiation and radiant heat is reflected back to the outside. However, the transmitted light is again discolored by the colour of the glass. The reduction in transmitted light has to be compensated by increasing the extent of glazing which again contributes to visual disturbances as a large area is exposed to view. This is clearly evident by the fact that in every such situation the user always tend to draw the curtains fully during the day. Therefore in terms of energy efficiency, clear glass is the most suitable glazing material for windows. Body tined glass could be used in situations where energy efficiency can be sacrificed for the sake of outlook of the building. However, this is not justifiable.

5.0. LIGHT CONTROLLING DEVICES

Light controlling devices are either integral components of apertures or attachments in buildings which help to keep direct rays of the sun away from the interior. Moreover, they provide protection from rain and sometimes influence the pattern of air movement in the interior space. Light controlling devices and shading devices can be devided into interior and exterior types. The fact that sun light within a building contributes to solar heat gain, care should be taken in choosing between the interior and exterior types of shading. In this respect, exterior shading devices are more efficient when both lighting and cooling are considered as equally important.
The most common light control and shading concepts are;

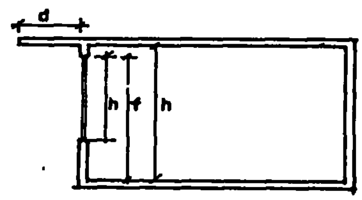
- overhangs and external overhangs
- light shelves
- horizontal louvres and blinds
- vertical louvres, fins and blinds

Overhangs are used in conjunction with side lighting concepts and are often an extension of the roof plane passing the plane of the aperture. For proper sun control, an overhang must shade as much of the glazing as possible, specially during the period when the sun makes the maximum angle with the vertical. A sun path diagram in relation to the location would be the ideal guide in this respect.

Source: Daylighting Design and Analysis, Robbins C.L

The overhang size (d) can be determined from the height of the aperture to be shaded (h) and the solar altitude (θ) such that $d=h/\tan\theta$(see Fig.7)

A light shelf splits the aperture in to a view light below the shelf and a clear storey light above the shelf. Placing the shelf inside or outside the



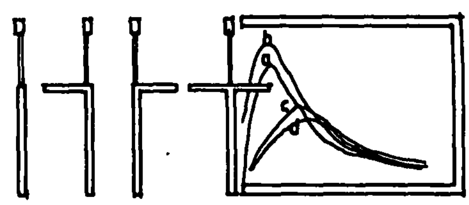
Nomenclature used for a room with an overhang

Fig 7

building can change the characteristics of the performance considerably.

Interior light shelves provide less penetration than exterior ones under all sky conditions, excluding the effect of the sun. With direct sunlight, it shades a portion of the interior but affects the cooling load, since it does not shade the glazing.

Exterior light shelves improve the penetration of daylight in to the space under all sky conditions. They act as shading devices and reduce solar gain. Sunlight reflected on a top surface penetrate into the building (see Fig.8). horizontal louvres and blinds could function on all facades. They control direct sunlight and reduce sky glare. Externally placed louvres function better in lowering cooling loads (see Fig.9).

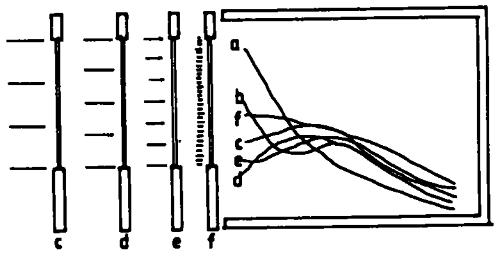


impact of daylight penetration in a sunless room with various lightshelves when $\overline{H} = 1{\cdot}5:1$ $\overline{V} = 1:1$ $\overline{H} = \infty:1$ (solar altitude = 30° solar azimuth = 0) and $\overline{D}$ is varied as a) no light shelf b) + $\overline{D} = 1:1$ c) − $\overline{D} = 1:1$ d) $\overline{D} = 2:1$

Fig 8

Source: Daylighting Design and Analysis, Robbins C.L

With regard to the use of light controlling devices in top lighting concepts, the application would be more towards controlling the direct sunlight falling on the work surfaces than improving the efficiency of the design.

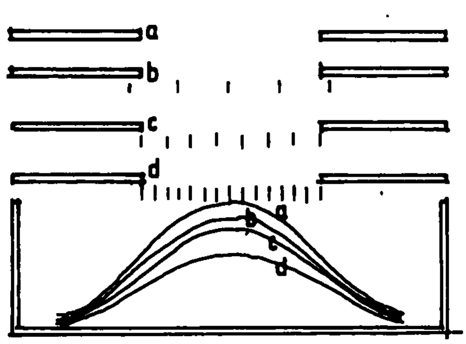


Perfomance of horizontal louvers and blinds at different $\bar{D}$ ratios.
a) $\bar{D}$ = 1:1, extended over hang (not illustrated)
b) $\bar{D}$ = 0·5:1 (Not illustrated) c) $\bar{D}$ = 0·25:1
d) $\bar{D}$ = 0·20:1 e) $\bar{D}$ = 0·17:1 f) $\bar{D}$ = 0·03:1 (blinds)

Fig 9

Source: Daylighting Design and Analysis, Robbins C.L

The sun controlling devices to be adopted therefore, should not totally stop the flow of direct sunlight into the interior, but help to change its direction so as not to cause glare or contribute to a brightness imbalance in the interior. Also when the sun is directly over such aperture, the louvre will allow the light to pass through the lower levels at which such light could be advantageously utilized through reflection of different surfaces (see Fig.10).



Illumination variation from skylight varying louver spacing as a) no interior louvers. b) spacing = 1h. c) spacing = 2h, Spacing = 4h.

Fig 10

Source: Daylighting Design and Analysis, Robbins C.L

Adjustable parallel baffles similar to a Brise Soleil (an external sun breaking device provided in opening) can be mounted below horizontal apertures to intercept the direct rays of the sun and diffuse them. The baffles should be adjustable to match the movement of the sun during different periods of the year and should therefore be positioned in relation to the sun path. This type of device also reduces the heat gain to about one third and thereby contributes to the efficient use of energy in buildings.

However, in all the possible solar control methods, there is still an appreciable contribution to heat gain within a building from natural lighting, due to the admittance of high frequency ultra-violet rays and the infra-red rays.

It is not appropriate to change size, position and location of the openings solely for the purpose of providing good ventilation across a room, since obtaining maximum daylight penetration is also a determining factor. Therefore, certain external features could be utilised in the building environment (e.g., providing ventilation through stack effect and landscaping modified through careful laying out of vegetation and water bodies etc.) to induce air movement and thereby causing a satisfactory thermal condition. It should therefore be clearly borne in mind that providing thermal comfort should always be considered as a part of any delighting design.

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Dr. Ranjith Perera is a Senior Lecturer at the Department of Architecture at the University of Moratuwa and Archt Sashikala Ranasinghe was a M.Sc. Student at the Department in 1995/6. Presently Archt. Ranasinghe is reading for a M.Sc. Degree in Architectureal Lighting at the Pennsylvania State University, USA.