Abstract
Attempts at maintaining satisfactory comfort levels within buildings have been made far back in history. In that distant past, several efforts were made to improve the thermal comfort of the indoor climate through various means, be it structural or mechanical. The intuitive use by the ancient Egyptians of vertical shafts through which evaporated water-laden air passes as a result of circulation of air over earthen pots filled with water as a means of evaporative cooling; and the ingenious central heating systems of the Romans to carry hot air through channels in walls and floors, in their colony in England serving as few examples. In recent times the need for structural as opposed to mechanical means of thermal control cannot be overemphasized especially in the tropics of sub Sahara Africa where steady supply of electrical power cannot be guaranteed to run modern mechanical air-conditioning systems, coupled with escalating running costs and attendant environmental hazards of ozone depletion. By far the most significant source of heat gain into a building, resulting in constant discomfort, is the solar radiation received indoors by direct penetration of sunlight through windows. One of the available methods of structural means of thermal control, in the reduction of solar heat gain through windows is the use of external shading devices. In the light of the above, this paper takes a look at the effective utility of these external shading devices, through the proper choice, and efficient design of these devices, in order to encourage its use as an appropriate alternative to any design not contented with substituting mechanical means of air-conditioning for good design.

Introduction
A building in a sense is a buffer for man against his external environment, particularly his thermal environment. The quest for thermal comfort from times past led to a large number of highly diverse building forms in various parts of the world. The provision of wind catchers in the hot humid regions of the province of Sind in Pakistan, the vertical shafts with earthen pots of water as means of evaporative cooling used by the ancient Egyptians and the ingenious central heating system of the Romans in England to carry hot air through the walls and floors are but few examples of the intuitive environmental design of centuries.

Today, however, a large volume of scientific data relating to various parameters that influence our thermal environment has been collected to enable us to make buildings with more efficient shelters against the rigors of climate.

The Need for Structural Controls
The power that determines our thermal environment is the sun. The amount of solar radiation received indoors by direct penetration of sunlight through windows is usually the greatest source of solar heat gain. In case of glazed windows, the sunlight penetration can raise the indoor temperature well beyond the outdoor by what is known as the "green house effect". The sunlight comprises mainly short-wave heat radiation to which a window glass is almost transparent. The in-coming radiation is absorbed by the wall surfaces, which in turn emit long-wave radiation, which once entered the window is trapped inside making it a constant source of discomfort.

In order to minimize or correct this discomfort and to reduce solar heat gain in buildings, most people have resorted to using mechanical means. The use of massive air conditioning plants to correct an ill-conceived environment does not differ in principle from the use of a masonry facade to hide an unnecessarily ugly concrete structure. The need for structural controls can be summarized as follows:

- Control of glare and solar heat gain.
- Eliminate the use of massive air conditioning plants to correct an ill-conceived environment.
- Utilization of daylight illumination
- To ensure the best possible indoor thermal conditions by relying on structural (passive) controls,
which may obviate the need for any mechanical controls.

**Shading of Openings/Daylighting**

One of the principal functions of a window is to provide natural light. In hot climates or at least during the hot seasons, direct sunlight should be excluded; lighting in these cases is provided either by reflected sunlight or by light from an overcast sky. In cool and cold climates the main criterion for natural lighting is to ensure that there is sufficient light on heavily overcast days when the sky brightness is low. In warm and hot climates, it is necessary to prevent excessive light from entering when skies are bright or when reflected sunlight from the ground is intense.

Excessive lighting can cause unpleasant glare. Glare may result from strong contrasts in light level, or from high absolute levels of light. To give protection from glare caused by direct sunlight it may be necessary to provide shading devices or shutters to exclude direct sunlight.

Direct sun glare cannot be easily avoided by the use of tinted low-transmission glasses because it will reduce light levels below an adequate standard for natural light at times when direct sunlight is not a problem. However buildings which are well orientated with respect to the sun are much less liable to suffer from direct sun glare.

Windows should be located to give a view of the sky rather than the horizon or the ground. Windows in composite climates are subjected to bright overcast skies in the warm humid season, and strong reflected sunlight in the hot dry season. A traditional solution to this problem is the screen, which reduces glare at the same time as allowing free air movement. This is more effective than tinted glass, which prevents air movement.

**Solar Radiation Control**

Heat gain and glare from direct solar radiation can be controlled by preventing direct sunlight from falling onto glazed areas of building façade.

An understanding of the geometry of the sun's movement relative to a given location on the earth's surface will make obvious the need for each facade of a building to be designed independently for its particular orientation i.e. there is an inherent rationale in each façade of a building being different from adjacent façades.

Windows have a major effect on the internal thermal environment owing to the many different functions they perform and also play a vital role in relation to the visual environment.

In many climates the term window and glazed area will not necessarily be synonymous. In temperate climates windows might be partially glazed and partially open-able. But in a warm humid climates windows might be partially glazed and fully open-able, opaque and possibly insulated louvers being used for part of the opening. In hot dry and Mediterranean climates, fully open-able and fully glazed openings are the rule.

The need for shutters will also vary. In temperate climates, internal curtains are normally sufficient to control solar radiation. In warm humid climates shutters may not be necessary if roofs have adequate overhangs to shade openings. In hot dry, composite and Mediterranean climates, shutters are usual as they provide protection from solar radiation and ground glare.

**Designing of Shading Devices to Prevent Radiation**

When conditions are within or above the comfort zone, solar radiation can cause or increase discomfort, therefore openings, especially glazed openings should be protected to prevent the penetration of direct solar radiations at times when temperatures are within or above comfort zone. When temperatures are below the comfort zone solar radiation can be beneficial as it can raise internal temperatures to create comfortable conditions.

Openings can be orientated to obtain the benefit of solar radiation at these times. But excessive solar radiation penetrating large glazed openings may create uncomfortably hot internal conditions. Solar radiation may be excluded by roller blinds or shutters, but the shutter will transmit some of the incident solar radiation to the interior, as well as excluding light, air movement and I blocking of view of the exterior.

For most orientations it is possible to design an external shading device which will allow a view of the exterior and admit light and air movement at the same time as excluding direct solar radiation.

**Procedure for The Design of Shading Devices**

- Temperatures at different times of the day must be found to establish when shading is required.
• Location of the sun at times when shading is required.
• Proportion of the shading device should be chosen using an overlay, which shows how the sun can be shaded.

The Location of The Sun When Shading is Required

The times beyond which shading is required can be plotted on the sun path diagram for the appropriate latitude. Any projection of the sky vault may be used for the sun path diagram. This can be prepared by hatching those areas of the sky across which the sun passes when shading is required. (See Fig. 1). With this design decisions on orientation, window shape and shading can now be made. The sun path diagram will indicate, if there are orientations, which will experience low-angle sun at times when shading is required. Westerly orientations often receive solar radiation when air temperatures are high. For this reason west-facing windows are also difficult to shade when mornings are warm or hot. The sun path diagram also indicates the large areas of the sky across which the sun will never pass. Windows orientated towards these areas will require little or no shading. The diagram shows the area of the sky across which the sun passes when temperatures are cool or cold. Moderate quantities of solar radiation from these areas of the sky will contribute to the creation of comfortable internal conditions, if windows are orientated to take the advantage of this radiation. An example of a general analysis of a hatched sunpath diagram is shown in Fig 2.

The general shape of the window may also be related to the shading requirements, although ventilation, lighting, view and other functions and aesthetic requirements will also have to be taken into account.

In general, the sun path diagram will indicate that horizontally proportioned window?--suitable on walls, which face towards the equator, while vertically proportioned windows can be used on walls, which face away from the equator.

Determining the Proportions and Dimensions of A Shading Device

Once the orientation and general shape of the window is decided, the detailed design of the shading device can be made. The angular proportions of the device can be determined by the use of a shadow angle protractor. This shows the parts of the sky that are completely shaded by vertical and horizontal projections of different proportions (see Fig. 3).

The curved lines on this shadow angle overlay represent a number of hypothetical sun paths. If the sun were to follow these paths it would appear to have the same altitude when seen in the sector of the azimuth indicated by the arrow at the base of the overlay. The area above one of the curve j lines is shaded by horizontal overhang the extent of which is defined by the vertical shadow angle indicated. This vertical shadow angle is the angle subtended at the lowest edge of the glass from the horizontal up to the outside edge of the horizontal overhang.

The vertical lines on the shadow protractor represent the limits of the sky vault that can be seen from the window with vertical fins, which project from the side of the window. The extent of these fins is defined by the horizontal shadow angle, i.e. the angle measured in plan and subtended at the edge of the window, from a line perpendicular to the plane of the glass to the edge of the vertical projection (see Fig. 4).

If the projection on the two sides of the opening are not equal, there will be two different: horizontal shadow angles for the two sides of the window. Even when there are no additional projections from the sides or the head of the window, the thickness of the wall will prevent the sun from shining through the window when the shadow angles are large.

The shadow angle overlay placed on top of the sunpath diagram as shown in Fig 5 only covers half of the sky, since the window only faces half of the sky. The overlay can be moved to the right or left until the appropriate orientation is indicated by the azimuth on the sunpath diagram, which is under the arrow on the overlay. If the orientation of the wall is to be chosen, the overlay can be moved until the most favourable orientation is found. With this the appropriate vertical or horizontal shadow angle can now be chosen to exclude unwanted solar radiation. When the sun passes high in the sky opposite the window, a horizontal overhang can be used to exclude the sun.

But if it is shining from one side of the window a vertical projection may be more effective.

When the sun shines from high in the sky opposite the window and later from the side of the window, overhangs and side projections can be used. In this case there will be a number of alternative combinations of vertical and horizontal shadow angles, which will effectively shade the sun.

There may be situations where the angles indicated by the shadow angle overlay will result in excessively large projections. In this case it may be necessary to allow a small area of sunlight to fall on the window for a short
period of time rather than accepting shading devices that are too large. Horizontal overhangs should extend beyond the limits of the opening in order to exclude sunlight that falls at an angle to the wall of the plan.

It is possible to use a number of small louvers rather than large ones to achieve the same shading effect. For windows that are orientated close to west, closely spaced vertical louvers may be the best way of excluding sunlight. Where both horizontal and vertical shading are required, egg-crate louvers may be used. Louvers to be used must be light and reflective to avoid absorbing and re-radiating the heat through the window. Hot high thermal capacity louvers in front of the window will "pre-heat" the air that may be needed to provide cooling. Shading devices that not only exclude direct solar radiation, but may also reduce sky glare, provide protection from rain, and influence patterns of air movement within the room are most advisable.

For all these reasons horizontal projections are preferable in the warm humid tropics as they provide maximum protection from sky glare and rain, with minimum interference with air movement. And for hot dry conditions, vertical louvers allow a view of high angle sky, while slightly reducing ground glare and the effect of hot dusty winds.

**Shading Devices**

There are three basic types of shading devices:

1. Vertical Devices
2. Horizontal Devices
3. Egg-crate Devices

**Vertical Devices:** Consist of louver blades or projecting fins in a vertical position. This type of device is most effective when the sun is to one side of the elevation, such as an eastern or western elevation. A vertical device to be effective when the sun is opposite to the wall considered, would have to give an almost complete cover of the whole window (See Fig. 6).

The cut-off angle of a vertical shading device is defined as the horizontal shadow angle, which gives complete shading of the opening (see Fig. 7).

**Using of Vertical Shading Devices**

If the vertical shading devices are fixed at a normal angle to the wall of a western facade, sunlight will enter freely throughout the year. For it to be more effective, the horizontal shadow angle required would be of the order of 29°.

**Horizontal Devices:** Consist of louver blades or projecting fins in horizontal position. It may be canopies, horizontal blades, externally applied Venetian blinds. This type of device is most effective when the sun is opposite to the building face considered, and at a high angle such as for north and south facing walls. To exclude a low angle sun, this type of device would have to cover the window completely permitting a view downwards only. See Fig. 8.

The cut-off angle for a horizontal shading device is the vertical shadow angle that gives complete shading on the opening. See Fig. 9.

**Egg-Crate Devices:** These are combinations of horizontal and vertical elements. The many types of grille-blocks and decorative screens may fall into this category. The design of a suitable shading device is basically the finding of a shading mask that overlaps the overheated period with as close a fit as possible. The combination of vertical and horizontal shading devices will perform the function of vertical/horizontal devices.
The shading mask of an egg-crate device can be prepared by combining the masks of horizontal and vertical devices (see Fig 10). If the sun lies anywhere within the portion of the solar chart which is hatched, direct sunlight will not fall on the window opening (see Fig. 11).

An egg-crate device allows effective view of the external environment, reflected light as well as free air movement.

**Fenestration Design of Modern Buildings (Performance of Shading Devices)**

Internationally, few architects succeed in producing fenestration designs that effectively control the penetration into modern buildings, of direct sunlight with its accompanying glare and heat load bearings. In order to arrest this ugly development it is unequivocally necessary for architects to be conversant with the following basic characteristics of some shading devices.

The shading masks which are used in knowing or in determining the effectiveness of any shading device are illustrated in Fig 12. It should be noted that a particular shading mask can be obtained from several different designs of shading devices. See Fig 12 (1 - 5).

Although the shading-masks of devices (1 - 5) are the same, the shading devices are different from each other. A creative designer therefore enjoys a great deal of freedom in their design.

Simple overhangs such as types (1-5) Fig 12 are useful for facades facing the equator. At latitudes remote from the equator the sun's altitude is low during the cold season months and horizontal overhangs when used on openings facing the equator permit sunlight to enter the openings. But during the hot season, the solar altitudes are relatively higher; hence a simple horizontal overhang on a façade facing the equator can provide the necessary effective screening.

From the point of view of daylighting, tiered horizontal devices such as 3-4 might be found to be preferable, because the inter-reflection of light between their surfaces reduces contrast glare for the occupant of the room behind. Types 5 and 6 have the advantage of permitting air circulation between the underside of the shading devices and the opening; thus helping to prevent temperatures building up in excess of air temperature.

The vertical sun breaks, with their radial masking characteristics, are generally effective on east or west directions. Used in conjunction with horizontal sun breaks they can provide protection to the opening in any orientation with varying degrees of efficiency and redundancy.

**Materials Used for Shading Devices**

For proper effectiveness and durability of any shading device, the material should be fully considered, since the shading of glass by external sunscreen remains a most effective method of controlling the influx of direct solar radiation. The following are some of the materials for shading devices and their properties:

1. Concrete-heavy, absorbs dirt, liable to damage, large tolerance required.
2. Cast aluminum- has to be painted; castings are expensive.
3. Cast iron- can be enameled.
4. Stainless steel- complicated burnishing would be required to keep it clean, problems always occur on the welded joint; easily scratched and very expensive.
5. Steel- vulnerable to the elements, oxidation destroys surface, costly to install and maintain.
6. Bronze- excessively expensive and difficult to maintain.
7. G.R.C.- easily moulded to required shape and can be fabricated, little thermal movement, easily washable surface, will withstand normal wear and tear.
8. Timber- needs special treatment, very expensive to maintain.
Conclusion

In good design a building should operate without the need to resort to a mechanical (active) means of thermal control or air conditioning. This is of particular importance in a country like Nigeria situated in a warm and humid tropical climate where the air temperature and humidity are seasonally high and create situations where human comfort demands the application of air conditioning.

In the absence of structural means of thermal control through adequate fenestration design and the correct use of shading devices, the only option left is the use of mechanical air conditioners to achieve comfort.

In Nigeria, as in many other developing countries, there is regular shortage of electricity supply causing long power cuts and making it impossible to rely on the possibility of using mechanical air conditioners as a means of thermal control. Mechanical air conditioner could also mean capital investment in equipment and a higher energy and maintenance costs during operations. From a broader perspective, the generation of electricity is achieved through the burning of fossil fuels (petroleum, gas etc), which results in both regional and global pollution problems.

A structural means of thermal control (passive control) depends largely on natural means, i.e., solar shading, cross ventilation and appropriate building design.

In good architecture, therefore, the building envelope should effectively synthesize all of the design parameters including structure, construction, thermal comfort, the lighted environment and services, with optimal capital recurrent costs in both money and energy terms.

References


PART OF THE SKY ACROSS WHICH THE SUN NEVER PASSES

PART OF THE SKY ACROSS WHICH THE SUN PASSES WHEN AVERAGE AIR TEMPERATURES ARE COOL OR COLD.

PART OF THE SKY ACROSS WHICH THE SUN PASSES WHEN AVERAGE TEMPERATURE ARE COMFORTABLE.

PART OF THE SKY ACROSS WHICH THE SUN PASSES WHEN AVERAGE TEMPERATURES ARE WARM TO HOT.

FIG 1: HATCHED SUNPATH DIAGRAM

WINDOWS FACING THIS DIRECTION WILL RECEIVE LOW ANGLE SUN WHEN AIR TEMPERATURES ARE TOO HOT IT WILL BE DIFFICULT TO SHADE THE SUN WITHOUT COMPLETELY BLOCKING THE VIEW FROM THE WINDOW.

WINDOWS FACING THIS DIRECTION WILL RECEIVE SOLAR RADIATION WHEN AIR TEMPERATURES ARE TOO HOT. BOTH FROM HIGH ANGLE SUN DIRECTLY OPPOSITE THE WINDOW AND LOW ANGLE SUN FROM THE WEST, A VERTICAL SHADOW ANGLE OF 35° IS REQUIRED.

WINDOW FACING THIS DIRECTION WILL RECEIVE MORNING SUN WHEN AIR TEMPERATURES ARE COOL, AND A LIMITED AMOUNT OF RADIATION WHEN TEMPERATURES ARE ABOVE THE COMFORT RANGE, A SHADOW ARE ANGLE OF 55-60° WILL EXCLUDE RADIATION DURING THESE TIMES.

WINDOWS FACING THIS DIRECTION WILL RECEIVE MORNING SUN WHEN AIR TEMPERATURES ARE COOL WITH LARGE GLAZED AREAS. THIS RADIATION MAY RAISE INTERNAL TEMPERATURES ABOVE THE COMFORT ZONE EVEN THOUGH EXTERNAL TEMPERATURES ARE COOL. IT MAY ALSO CAUSE GLARE.

FIG 2: ANALYSIS OF THE SUNPATH DIAGRAM
Window oriented 10° to the west of south for latitude 44°N

1. Low angle sun in winter may cause glare.
2. The area of the sky across which the sun passes when the air temperatures are within or above the comfort zone.
3. High angle sun is shaded by a horizontal overhang (vertical shadow angle 55°).
4. Low angle sun from the west is shaded by a vertical projection (horizontal shadow angle 45°).
5. Sunpath for June is complete shaded.

Fig. 5: Shadow angles on the sunpath diagram.
SHADING CHART INDICATING THE ADDITIONAL AREAS OF THE SKY WHICH ARE SHADED BY A VERTICAL SHADING DEVICE ON ONE SIDE OF THE WINDOW ONLY.

FIG. 6: A VERTICAL SHADING DEVICE.

CUT-OFF ANGLE OF A VERTICAL SHADING DEVICE.

SHADING MASK OF A VERTICAL SHADING DEVICE OF CUT-OFF ANGLE = 45°. IF THE SUN LIES ANYWHERE WITHIN THE HATCHED AREA, IT WILL BE COMPLETELY SCREENED BY THE DEVICE. THIS SHADING MASK ASSUMES THAT THE SHADING DEVICE IS INFINITELY HIGH.

Fig. 7
A Horizontal Shading Device. Note that it projects beyond the window on plan to prevent the sun reaching the window beyond the ends of the shading device.

FIG. 8: Horizontal Shading Device

The cut-off angle of horizontal shading device = c

FIG. 9: The hatched zone shows the extent of screening provided by a horizontal shading device of cut-off angle = 45°. Sun within this zone will be completely screened.

A series of shading devices with the same characteristics as the device shown in FIG. 8.
FIG. 10: A SHADING DEVICE WITH VERTICAL AND HORIZONTAL ELEMENTS

SHADING CHART INDICATING THE ADDITIONAL AREAS OF THE SKY SHADED BY A COMBINATION OF HORIZONTAL AND VERTICAL PROJECTIONS.

FIG. 11: ECG-CRATE SHADING DEVICE.

SHADING MASK OF AN ECG-CRATE SHADING DEVICE.

EXAMPLES OF ECG-CRATE SHADING DEVICES.