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Reducing Heat-Load in Buildings through the Use of Solar Screens: Case Study of Bookshop House, Lagos

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Abstract: Technology advancement has ensured a better means of livelihood essentially in certain parts of West Africa, specifically Nigeria, where the climate is predominantly hot in most parts throughout the year. Air-conditioning has reduced the harshness of indoor discomforts to the barest minimum. It is no more uncommon to find it regularly in use in most homes and offices. Currently, the economy has the centrality of its power supply hinged on generator plants. The enigma of the current situation is how this alternative problem has catastrophic after effects on the environment. This and many more add up to the greatest of all the threats now evading our environment and the world — Global warming. The threat of Global warming is real and the need to find less environmentally destructive sources of energy cannot be overemphasized. This paper is a contribution towards energy saving in buildings through the reduction of solar radiation incident on buildings. Sustainable Building calls for an integrated planning approach for operating buildings economically, substantially reducing their impact on the environment by reducing energy/power consumption, amongst others, and enhancing the well-being of their inhabitants. Only buildings that reconcile all of the above factors are fit for the future. A case study of the CMS (Catholic Mission School) Book Shop house in Lagos was carried out. The methodology involved the use of a solar chart and shadow angle protractor to determine the overheated periods represented by the shading masks and data collected. From this analysis, it was decided to accept the use of external sun shading and preliminary designs and specifications were prepared by the architects. The use of external solar screens made a saving of up to 75% of the energy input which would otherwise have been required by air-conditioning.

Key words: Heat load, buildings, solar screens, energy savings, shading masks.

1. Introduction

We are constantly producing huge amounts of energy in our daily life: it is not only possible, but also advisable to reduce such loads on the environment by means of properly designed houses. It is no news that buildings account for about 1/3 of global energy use, specifically in the UK, as much as 40% of energy consumed by buildings [1]. Proper designing should include positioning the structure suitably on the building site according to local conditions and applying architectural inventiveness to such elements as building methods, materials and elements, adequate insulation and daylight controls. Traditional architecture takes all this into consideration and is passive in approach: there was very little mechanical influence, if any at all [2].

Today, as architects, what we can do to contribute to energy saving, is to reduce the effects of solar radiation which contributes by far the largest heat gain in a building and therefore, by designing screens which are capable of excluding all unwanted solar radiation through windows, which can reduce a considerable amount of heat. In tropical areas, solar radiation is the main factor responsible for the thermal load of buildings. Lagos, for example has characteristics of high solar radiation and humidity, the former of which is the focus of this paper.

In this case, the most efficient way to reduce heat gains in buildings is to control and minimize the solar radiation absorbed by the building envelope. The walls, roofs, windows and floors are mediums of heat transfer and care should be taken in the construction and

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specification. Though the orientation of roofs has very little effect on heat gain [3], the roof material itself, the color and insulation type could be of considerable impact. The same goes for windows. Exterior shading devices will therefore bring significant reductions, they are very effective, whether fixed or moveable, manual or automatic and they vary in cost, durability, appearance and performance. The general advantage of using external controls is the obstruction of solar radiation before it enters the window. All shading devices, the exception of those which are fully retractable, reduce the effective light –admitting area. Fixed shading devices such as overhangs, fins, or various types of shade screen materials can be mounted externally (i.e., outside glazing) and incorporated into the architectural design of the building envelope. These inhibit sun penetration but allow some view of the sky, so that daylight can be admitted. Horizontal overhangs are effective for south facing windows (North facing in the Southern Hemisphere) while vertical planes as sun breaks can be effective for east- facing and west-facing windows.

The focus of this paper is the reduction of heat gain in buildings through the use of solar screens, and it will be discussed together with the benefits of solar control in the tropics and a means of achieving this will be proposed.

2. Study Area

Climatic zones in Lagos, Nigeria, According to Ref. [4], there are seven building/climatic zones in Nigeria (Fig. 1), with differences in climate sufficient to create definable boundaries. These run approximately east-west across the country with the first two in the lower latitudes, covering the hot-wet area from the Atlantic seaboard to just above Ibadan, through Lokoja and below Makurdi. The second and third zones cover the middle belts as far as the Jos plateau and from there to a line below Sokoto, Kano, and Maiduguri are the fifth and sixth zones which are the areas somewhere between hot-wet and hot-dry becoming increasingly dry at the Sahel which continues into Niger.

This information is more relevant to naturally conditioned buildings particularly those where the solar heat flow has to be controlled by closing windows to take advantage of the increasing dryness, and the gap between night and day temperature which can be exploited by adjusting the thermal capacity of the construction. This natural phenomenon can be used to save energy as is practiced in temperate climates,

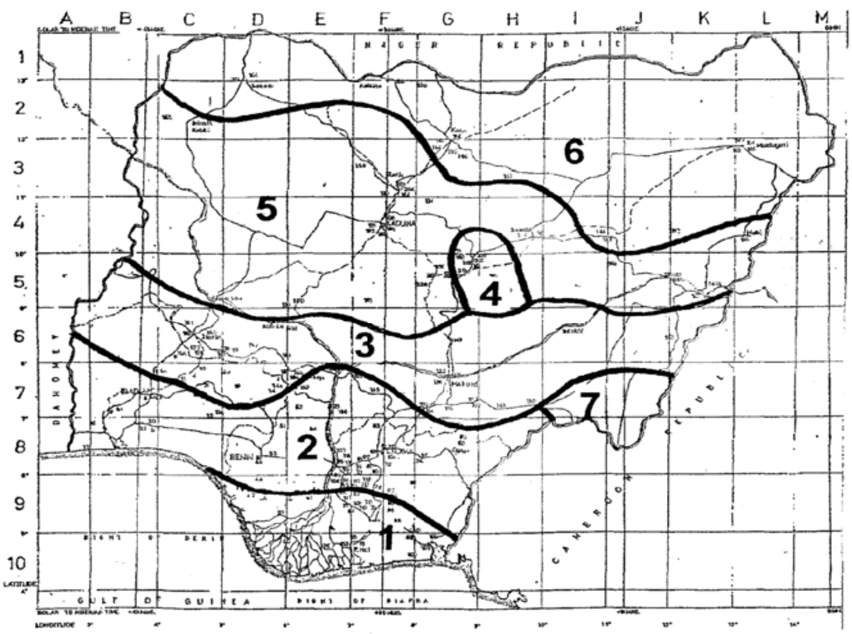

Fig. 1 Climate/Building zones.

3. Literature Review

3.1 Building Factors Which Influence Energy Requirements

Building factors which influence energy requirements can be classified under the following headings:

- Size and shape: generally, a larger building will require more energy to cool than a smaller one because of the volume of extra space to be covered;
- Orientation: building orientation affects the air conditioning/heating energy requirements in two aspects, by its regulation of the influence of solar radiation and ventilation effects;
- Planning & organization: areas where the layout will influence are, grouping of spaces, interaction of spaces, ceiling height and space volumes well as buffer zones;
- Thermo physical properties: these properties of materials affect the rate of heat transfer in and out of a building. They are thermal resistance, surface convective coefficient, absorptivity, reflectivity, emissivity, and heat capacity;
- Window systems: the size, location, shape, and orientation of glazed areas in a building will have a critical effect on both the heat gains and solar gains of a building because glazed areas have the highest heat gain per unit area and the major proportion of solar gains are also through windows;
- Construction detailing: in terms of methods and material usage and it has a significant effect on heat gains or losses.

Effective control of solar load, transmitted heat, is a precondition for a successful passive cooling concept in design.

According to Ref. [5], the amount of transmitted heat of transparent areas of a building envelope is determined primarily by:

- The size of the glazed areas;
- The orientation of the glazed areas with respect to the sun;
- External obstructions by surrounding buildings, trees, etc.;
- Glazing properties;
- The properties of sun-shading devices;
- How they are operated.

3.2 The Importance of Solar Loads

Effective solar control is imperative in order to reduce solar heating loads to a point where the usual indoor thermal comfort expectations are met without active air-conditioning. This is a challenge in warmer climates. It is important for offices as well as residential buildings because of the prevalence of computers which require both glare protection, control of internal heat loads, as well as maintaining a view of the outdoors. Without effective solar control, the solar heat load will be significantly larger than the typical internal heating loads in offices [6]. Sun-shading devices can effectively reduce the total energy transmittance of a glazed area.

Solar load control, despite its severity, is often excluded during the early design phases of a building. Buildings with large glazed areas and external sun-shading devices, the latter dominates the external appearance, or front elevation most times, and indoor to outdoor transparency is reduced. Therefore solar control should be determined in the initial stages alongside basic parameters and design concepts by all specialists involved, as part of an integrated planning approach. To adequately provide solar control, the two fundamental principles to apply are:

- Limitation of Solar loads — by indirectly reducing the heating of the room, delaying the further heating during warm temperatures;
- Protection against direct irradiation by the sun- this is undesirable for work environs, so there's a need to prevent direct solar radiation from coming into a space or reduce it very strongly.

3.3 Solar Shading and Potential Benefits in Energy Savings

A solar shading system, when specified is a functional and affordable component of sustainable building design, it is a key element of the exterior building envelope. Exterior solar shading is essential to building performance. When the appropriate shading material is specified, it allows for optimum daylight and views and a subsequent decrease in solar heat gain. Shading systems also diminish the amount of natural light that enters a building during the day. This in turn leads to a reduction in energy consumption and a healthier, more productive environment with improved indoor air quality [7]. In the choice of an external shading material the life-cycle performance, sustainable attributes, functionality and aesthetics of the proposed material should be taken into account.

Solar shading devices have evolved over time, and now come in different kinds with improved performance and aesthetics as well as sustainability.

A US Department of Energy model carried out a research on the energy and financial impact from the installation of a mesh screen with 50% coverage onto a 30-storey commercial office building with clear, double-glazed windows. The results from the study showed a considerable decrease in energy costs. More specifically, the study predicted an energy savings of US$94,000 yearly for the commercial building that was analyzed, due to the addition of the metal-fabric screen. The study is significant in that it provides concrete evidence of the solar shield functionality of Cambridge metal fabric, demonstrating its ability to dramatically reduce building energy costs. Also, the CSBR (Center for Sustainable Building Research) at the UMN (University of Minnesota) focused on external shading devices and their impact on energy use and glare control in a commercial building [8]. The study, titled "External Shading Devices in Commercial Buildings" took five types of shading conditions into consideration — none, vertical fins, shallow overhangs, deep overhangs, and a combination of overhangs and fins.

4. Methodology

This paper essentially examines the effect of the solar shading device of the Book Shop house designed with the view of reducing heat loads in buildings.

In order to design the solar shading device, the following steps have to be taken:

- Identify the site's geographical location. In this case, the site is located in Marina, Lagos;
- Establish the nearest sun path diagram to the location. Sun-path diagrams are constructed for site latitude from coordinates representing the azimuth and altitude of the sun, (otherwise known as the declination), at predetermined dates and hourly solar times (Fig. 2);
- Correction of solar time to clock time: the correlation of solar time to clock time depends upon the time for a particular location. It is important for relating the occupancy time of a building to the position of the sun. For example, the sunrise in Lagos is not seen until about 40 minutes after it has been seen in Maiduguri(Fig. 3);
- Establish the location in the climatic building zone, this information is more relevant to naturally conditioned buildings particularly those where the solar heat flow has to be controlled by closing windows to take advantage of the increasing dryness, and the gap between night and day temperature which can be exploited by adjusting the thermal capacity of the construction. This natural phenomenon can be used to save energy as is practiced in temperate climates [7]. Within the zones, the effective temperatures of particular locations are computed from average wet and dry bulb temperatures taking into account average wind speeds recorded there;
- Determine the overheated period of the day in order to establish the period when shading is required: The shadow Angle protractor (Fig. 4) is used in conjunction with the Sun path diagram, to determine

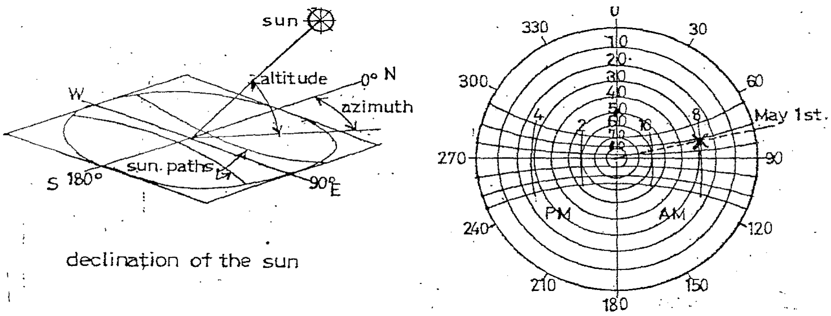

Fig. 2 The declination of the sun at latitude 4°N on May 1 at 0800 hrs solar time will be at an Azimuth of 76°E and an attitude of 29°N.

the amounts of horizontal and vertical projections required to exclude direct sunlight for any orientation at given latitude. The baseline represents the vertical surface to be shaded and the midpoint represents the observer's position. The radial lines represent horizontal shadow angles (H degrees) formed by Vertical projections and the curved lines (which are a function of solar declinations) represent vertical shadow angles (V degrees) formed by Horizontal projections, normal to the observer's position. The shadow angle protractor is laid over the Sun Path Diagram for the latitude and location of the base line, representing the vertical wall, oriented to the proposed angle of the building of the building on the site plan. It is then possible to read off horizontal vertical shadow angles which will exclude direct solar radiation during the overheated period of the day. The resulting profile is called "Shading Mask" in Fig. 5.

- Type of building or occupancy: whether the building is a house, office, school or factory enables us to define the occupancy period and thus the times when solar exclusion is needed;
- Orientation of windows/openings, as a general rule, openings are more easily protected if orientated north-south while those facing east-west are more

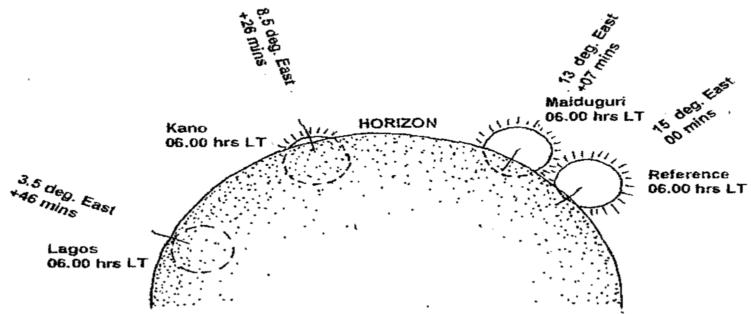

Fig. 3 Apparent sun-rise approximately at 06.00 hrs.

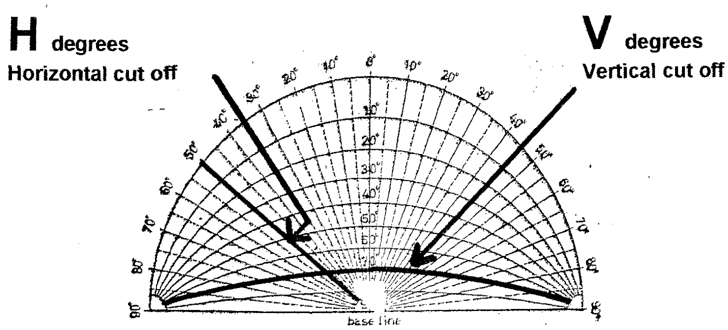

Fig. 4 Shadow angle protractor.

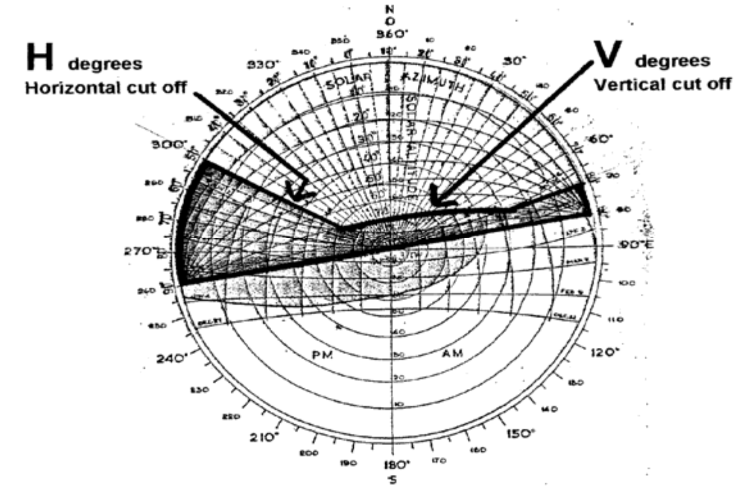

Fig. 5 Shading mask derived from the protractor overlay.

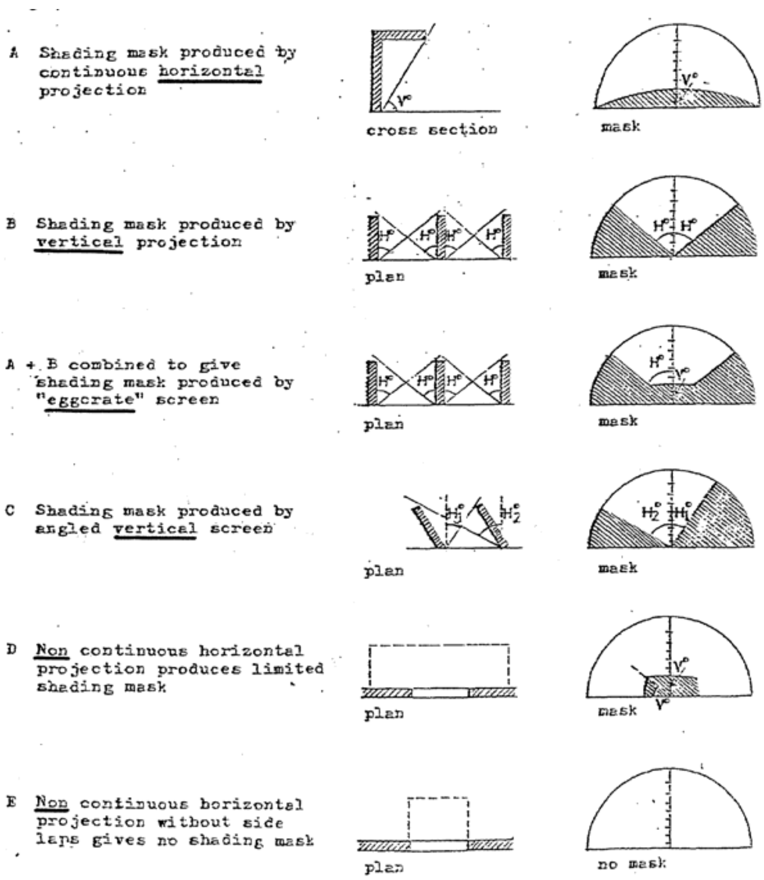

Fig. 6 Selection of openings and shading devices showing the shadow angles they produce.

difficult to deal with, however it is not always possible to obtain the ideal orientation and a solution has to be found, made more difficult where natural ventilation is a prime consideration. Below in Fig. 6 is a selection of openings and shading device showing the shadow angles they produce.

5. Results and Conclusions

The "Book shop House" Lagos, perspective in Fig. 7.

From this analysis, it was decided to accept the use of external sun shading and preliminary designs and specifications were prepared by the architects upon which tenders were obtained. Details and drawings are in Figs. 8–10.

Three alternative costs due to peak Air-Conditioning Loads and resultant capital and running costs in US Dollars for one office floor, as shown in Table 1.

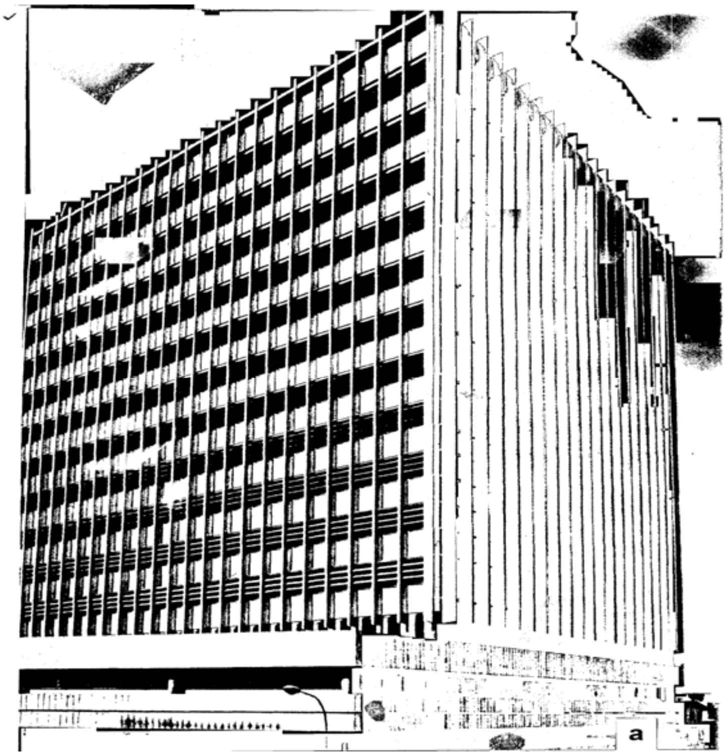

Fig. 7 A perspective view of the BookShop House.

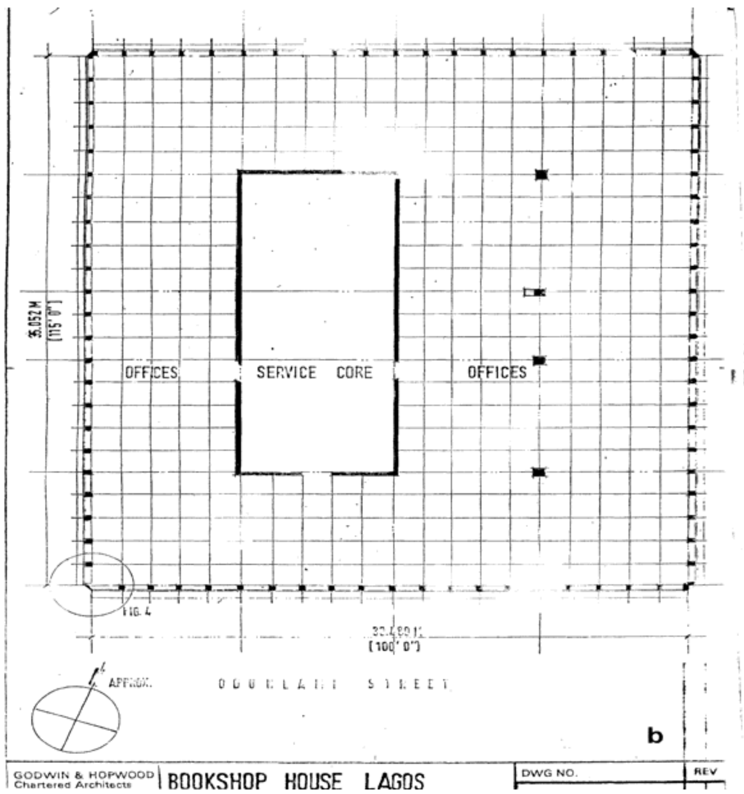

Fig. 8 Typical plan of bookshop house.

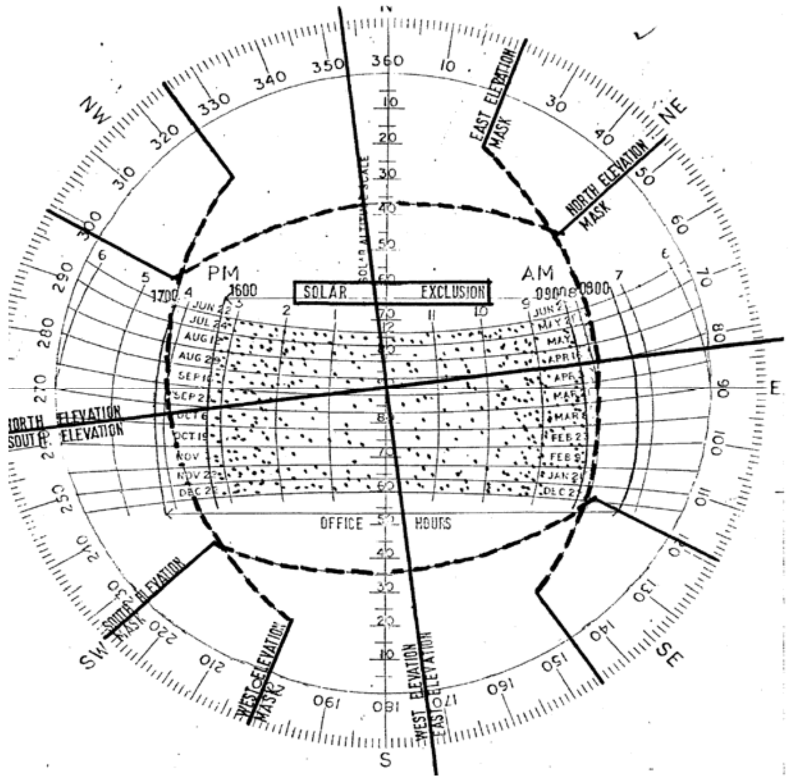

Fig. 9 Solar chart for latitude 7° north local time: 16miutes ahead of lar time.

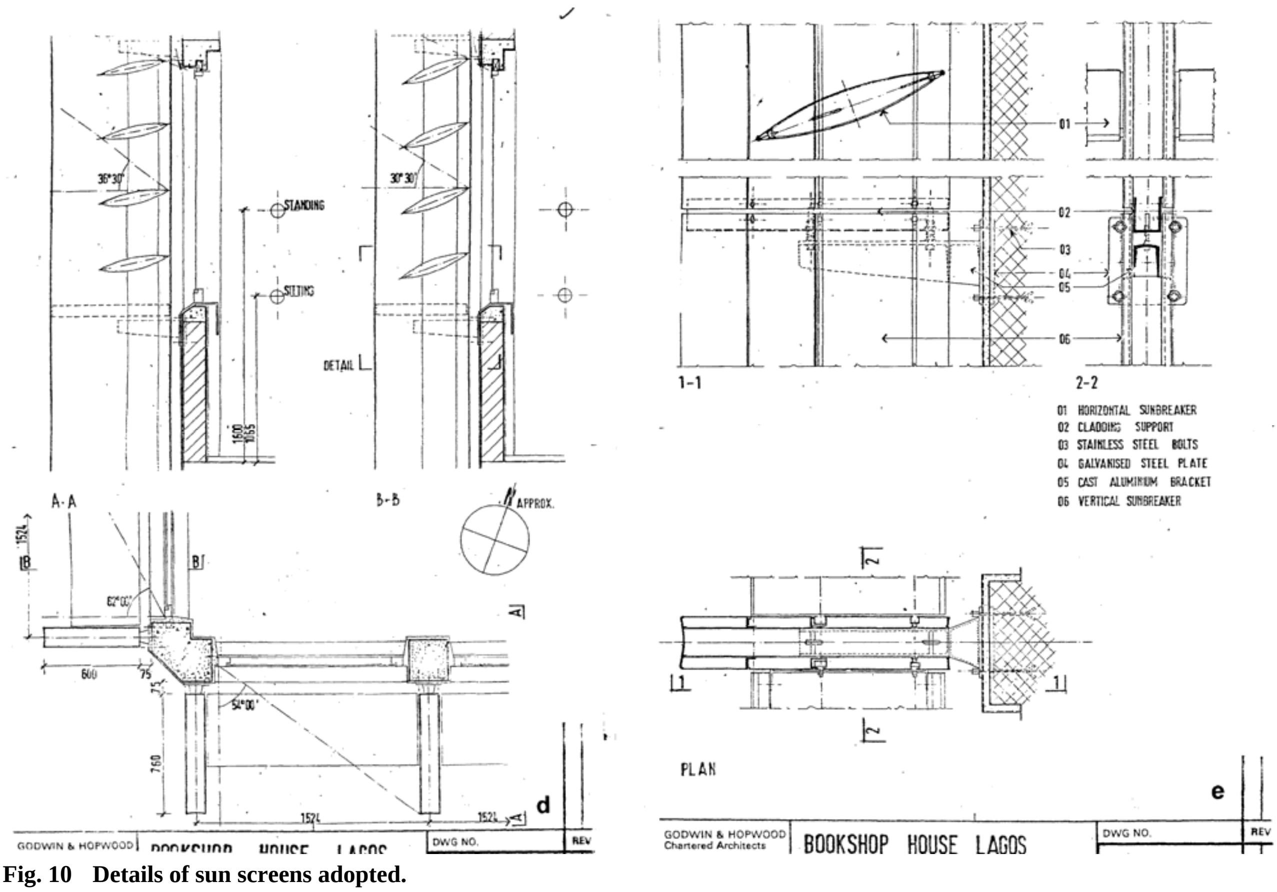

Fig. 10 Details of sun screens adopted.

Table 1 Three alternative costs.

Option	Reduction in solar load %	Tons of a/c required	Total capital cost in $ US	Running costs P/A $ US
1 None	0	167	167,000	9,419
2 Venetian blinds anti sun glass	52	80	106,197	4,521
3 Clear glass and ext. sun-breakers	85	25	67,129	1,410

Source: Ref. [9].

In naturally conditioned buildings, the use of effective sunscreen combined with induced air movement and/or thermal storage is probably the only way of bringing temperatures down to comfortable levels, by carefully designing to ensure both protection from the sun and ventilation. The use of ventilating panels which project out at an angle to catch breeze and exclude sunlight and sky radiation is ideal.

The above compares favorably with [7], which revealed that glass can be assembled in several layers to reduce solar radiation to under 40%, but very expensively, while reduction by effectively designed opaque screens, fixed externally can exclude almost 25% of the solar radiation and will be much cheaper to provide, with the added cost benefit that almost certainly can be manufactured locally. For the tropics, reducing heat loads is paramount as this hot condition is prevalent for most parts of the year and leads to discomfort or unpleasant indoor conditions requiring mechanical ventilation and air-conditioning regularly. With passive technologies like solar screen shading, buildings will naturally reduce heat gain by cutting off direct solar radiation from heating up the spaces, thereby creating cooler spaces. This is advantageous in the current pandemonium of climate change and global warming.

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