Solar Control using Openwork Walls: 
The Solar Applicability Range

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ABSTRACT: Most buildings in the tropics require the control of solar rays admission, as well as advantageous use of natural light and allowance of cross ventilation. One basic element to achieve this is the openwork brick, used to create comfortable environments. This is extensively used in the tropics due to its low manufacturing technology requirements and its reduced cost. The openwork walls have an immense sustainability potential, especially in modern tropical buildings, but research on its solar behaviour is scarce. This research evaluates the solar gain in perforated surfaces defining the “Solar Applicability Range”, a property useful to identify intervals of guidance where a perforated pattern shape will present a “Desirable Solar Gain Level”. In addition, the methodology developed gives valuable input in the geometric design of an element capable of presenting a “Solar Applicability Range” previously defined, introducing shade performance in the design of the openwork walls.

Keywords: openwork bricks, openwork walls, solar performance, shadow, tropical architecture

INTRODUCTION

Perforated surfaces represent one of the most economical ways to promote solar control without sacrificing natural ventilation. Vernacular architecture of many regions located in the tropics exhibit buildings’ envelope with this type of solutions. Big buildings of the past century offer several examples of application of openwork walls [1]. Since this type of solution is still valid, modern interpretations are numerous and the subject is far from being exhausted (Fig. 1).

The openwork walls have an immense potential creating comfortable environments passively conditioned, especially in the tropics. However there is little research about the openwork bricks solar behaviour and therefore such walls are often not designed according to principles of efficiency and sustainability, but of

Figure 1: The openwork elements are part of the architectural tradition of many places on the planet. Left: Cairo, 19th century or earlier. Right: Brasilia, 20th century.

Figure 2: Sunlight Spatial Dispersion. The openwork area exposed to solar radiation can be equal to an equivalent area window, but distributed over a larger area, its impact is lower in terms of light and heat.
constructional simplicity and visual appearance.

When an opening in a wall allows the entry of solar rays, the enclosure will present a sun incursion region. The decomposition of this opening in several openings gives rise to a set of small sunny locations with a higher spatial dispersion (Fig. 2). Although the perforations sum up the same area of the original opening, the impact in the indoor environment is lower in terms of light and heat [2]. Additionally, as the perforations become smaller, the shadow contribution of the planes that define the compartments is proportionately larger, which is why for a constant thickness, an openwork wall will always give origin to a lower solar incursion than a single opening of equivalent area (Fig. 3).

![Figure 2: Decomposition of a single opening into several openings.](image)

![Figure 3: For a constant thickness, an openwork wall will give origin to a lower solar incursion than a single opening of equivalent area.](image)

The Solar Geometry principles applied in the evaluation of openwork walls allowed to demonstrate that each perforation pattern has a different solar performance [3] which depends on latitude, solar access allowance, geometry of the perforation and especially, orientation of the plane which contains them. In the past, previous work analysed openwork elements with a diagnostic approach using shadow masks [3,4], but these studies have not been quantitative. Comparison of different openwork designs based on the amount of solar radiation that enable to enter, or the orientation ranges which would be inappropriate to apply, would help to obtain other results.

Knowing in advance the range of orientations for which an opening with a particular shape will have an adequate solar behaviour is the first step for the environmental optimization of the openwork wall. The variety of openings and possible orientations are immense and therefore a method has been developed to study the openwork walls to make possible their geometric enhancement, improving the shading level that can be achieved.

In any openwork wall, the geometric configuration of the openings is more important than the arrangement of the solid elements comprising the wall. If the desired maximum solar gain has been established, as well as the range of orientations advised for the use of openwork brick, hence it is possible to derive the parameters and geometric proportions of the openings of such walls.

**OBJECTIVE**
Define an openwork wall property called "Solar Applicability Range" in order to establish orientation intervals for which a perforated wall will provide certain level of shading.

**METHODOLOGY**
To study the effectiveness of solar control devices preventing the sunlight incursion through an opening, it is necessary to calculate the shaded area for every solar position during the year, regularly assuming no cloud covering. The procedure that allows comparative studies of the solar performance for any shape is named "Shading Device Evaluation Method" [5], but it has not been applied to the study of openwork bricks so far.

The calculations by which we have studied the Solar Performance Efficiency in various shading devices [6] are based on orthogonal projections in the direction of the opening or the working plane. It is a methodology suitable for openings with appreciable size, but that would require excessive computational power when applied without modification on an array of items.

To overcome this difficulty we decided to work with shadow masks and therefore in polar coordinates. The automation of such projections allowed the increment of the resolution of the analysis to the necessary degree to make quantitative assessments. The average time of sun exposure was obtained by superimposing a cloud of points that outlines the solar paths to a set of shadow masks produced from the geometrical transformation of the element under study.

The analysis procedure requires modelling the openwork element through three-dimensional drawings representing, one by one, all its partitions. Using the 3D model and from a point located behind the element, numerous projections are done toward a hemisphere representing the sky dome. Thus each flat polygon...
composing the openwork element representation is transformed into a spherical polygon, finally having a spherical representation of the complete object (Fig. 4).

On this spherical model the cloud of points representing the paths of the sun for the latitude under consideration is outlined. Using 1949 points calculated every 12 minutes, distributed throughout the solar trajectories every 5 days during half the course of a solar year. These parameters were enough for the level of resolution required for this study.

Finally, to distinguish the intervals when the solar rays will be getting through the opening under evaluation, it is necessary to make a polygon recognizing process to totalize the solar positions not included in the shadow mask. The number of unshielded solar positions during the year is enough to calculate sun exposure, giving a daily average in minutes of the sun's rays reaching the analysis point.

Counting unobstructed solar positions gives a value only valid for one orientation, the computer routines then stores such result, rotates the spherical polygons 10° and repeats the count in order to complete one orbit around the point of analysis (Fig. 5). The product is a list of 36 values of sun exposure that it would present the openwork element in all the possible orientations. Thus different perforation patterns comparisons can be made with ease (Fig. 6).

Having calculated the Solar Performance of different openwork elements, the resulting database was processed with respect to a reference value called "Solar Income Threshold." This is the highest degree of sun exposure
that can be considered as acceptable for the conditions of use and climatic characteristics of the place where the openwork wall will be built. This procedure helps to identify orientations which for a given geometric solution would result in values above or below the solar gain reference.

Grouping the results falling within the threshold values determines the "Range of Applicability Solar", i.e. orientations for which a pattern of perforations will present an acceptable level of sun exposure (Fig. 6). Broader ranges represent the possibility of wider assortment of orientations. Conversely, orientations exceeding the threshold limit should not use the openwork element under study, at least at the latitude under consideration.

RESULTS
Three groups of simulations were produced that allowed to calculate the variation of the "Solar Applicability Range" depending on the thickness of the wall. Thicknesses of 10, 15 and 20 centimetres were studied in 13 different rectangular openings with a ratio width/height between 4:1 and 1:4. All calculations were analysed under the same geographic latitude of 10° N. When studying from horizontal openings, through a square one, until reaching vertical slits, it was found that regardless of the ratio width/height every perforation shape efficiency increases with increasing the thickness of the surface where it is applied (Fig. 7). However, the increments do not follow a linear proportionality, hence an extreme increase in the thickness of the wall does not necessarily lead to an increase in the "Solar Applicability Range".

It was observed that increasing the wall thickness reduces the average daily solar exposure in a more noticeable way when the openings are elongated, whether they are vertical or horizontal. Doubling the thickness of the wall in openings with a ratio 1:4 and 4:1 reduces the sun exposure by a factor of three, while for the remaining openings changing from 10 to 20 centimetres in thickness reduces the sun exposure to less than half.

It is important to note the highest solar exposure observed with all thicknesses in almost all the orientations, were obtained by the square openings. Nonetheless, the square shape has the most favourable form factor of all rectangular openings, allowing to maximize light utilization while reducing natural ventilation losses by having less friction with the fins. However it is noteworthy that precisely this shape, having the worst solar performance, is applied more regularly.

The previous information was used to study the variation of the "Solar Applicability Range" for constant thickness, changing the width/height ratio of rectangular perforations with their fins perpendicular to the plane of the wall (Fig. 8).

It was observed that for a threshold gain of 90 minutes daily an openwork element with a horizontal slit and ratio 1:4 (Fig. 8. above) can be used in building walls of any orientation, in latitude 10° N, it will always present a satisfactory solar performance. The curve towards the east and west still has a margin of approximately 10 minutes of sun exposure remaining, and therefore element dimensions could even be adjusted, avoiding unnecessary solar obstruction.

Furthermore, a similar element vertically installed, would only be recommended for a range of orientations of 240°. Meanwhile a square shape, which is the one with the lowest Solar Applicability Range, would only be appropriate to build walls in a range of 180°, unequally distributed between north and south.

![Figure 7: Average Daily Solar Exposure caused by five openwork elements in all possible orientations in latitude 10° N. Above: holes in a wall 10 cm thick. Middle:15 cm. Bottom: 20 cm.](image-url)
A third and fourth set of simulations allowed to estimate the variation resulting from the "Solar Applicability Range" if the vertical fins of the openings were rotated 30° from the normal to the surface. There are two alternatives for this rotation: clockwise and counter-clockwise (Fig. 9). It has been noted that both spins resulted in double asymmetry in the solar behaviour of the element: On the one hand, the worst performances do not occur on the east-west axis anymore, but are redirected northeast and southwest if the rotation was counter clockwise. On the other hand, the clockwise rotation presented the worst performances located in the northwest and southeast quadrants. In both cases, the fins rotation angle did not derive an equal Solar Applicability Range rotation.

The second situation of asymmetry caused by the rotation of the fins has been the differences between both sides of the orientation ranges initially discouraged, which were aligned with respect to the east-west axis and originally had the same values. It has been observed that the rotation favoured the performance of openwork walls facing the northern hemisphere while being inappropriate for the openwork walls facing the south. However, counter clockwise turns are better for eastern facades, while the clockwise rotation favour the performance of walls facing the sunset.

**DISCUSSION**
All the carried simulations correspond to 10°N latitude, covering much of the Caribbean Coast of the Americas. For reasons of solar symmetry, numerical results obtained are valid for the opposite latitude, i.e. 10° S, corresponding to the northern coast of Peru. However, the recommended guidance ranges are totally different depending on the location if it is north or south of the Equator Line, including perpendicularly perforated openwork walls.

Due to the climatic stability of the equatorial zone, the "Solar Gain Threshold" can be considered constant. For this reason the processing database needed to
consider the separation of data with respect to the horizontal line, i.e. data above or below a reference value. A similar technique could be used to evaluate openwork bricks in areas with significant seasonal variations: it will be sufficient to classify the data with respect to a wavy line, which would represent the variation of the desirability of solar gain throughout the year.

It can be seen that the "Solar Applicability Range" is a sensitive magnitude, which changes with the orientation of the wall or the shape of the openings. As all values are relative to a single point located behind the openwork brick, this point must be positioned so that the results are representative. To achieve this, in all cases the point was located on the bisectors of the perforations, where the maximum sun exposure is expected.

Significant differences in the solar performance of the studied elements were observed. In all cases the highest solar incursion times were obtained by elements with ratio width/height close to 1. Proportions away from this shape resulted in reductions in the times of sun exposure, accompanied by increases in the "Solar Applicability Range".

CONCLUSION
The "Solar Applicability Range" is an useful value to determine the orientation intervals for which an openwork wall will exceed a given solar incursion level. Variations in the test procedure in order to include the solar incursion tolerance depending on schedules, calendars and rainy or cloudy seasons, is still necessary. It would help to continue improving the way of assessing the indoors presence of sunlight in the tropics.

Since doubling the thickness of an openwork wall depth requires the same amount of material as changing the ratio of the openings, hence the second choice will be the best design option from the standpoint of solar control. Changes in the shape of the openings, more than the thickness of the walls, are the way to reduce sun exposure times caused by the openwork walls in the tropics.

Rotating the vertical partitions of the openings by 30° to the normal of the wall is only meaningful in predominantly vertical openings. In square openings, the benefit is not significant and therefore the rotation angle should be greater than this. In predominantly horizontal openings the benefit of turning 30° is imperceptible.

With the exception of predominantly horizontal openings, by improving the geometry of an openwork brick to provide its best performance in a particular orientation, results in worsening its performance in other directions.

The obtained differences in the "Solar Applicability Range" for the two oblique openings families analyzed in this study have been rather drastic. Apparently 10° was a moderate distance with respect to the line of Ecuador, but certainly the design criteria for openwork elements required in tropical areas should be totally different no matter the climatic similarities between both sites, as long as they are located north or south of the Equator Line.

REFERENCES