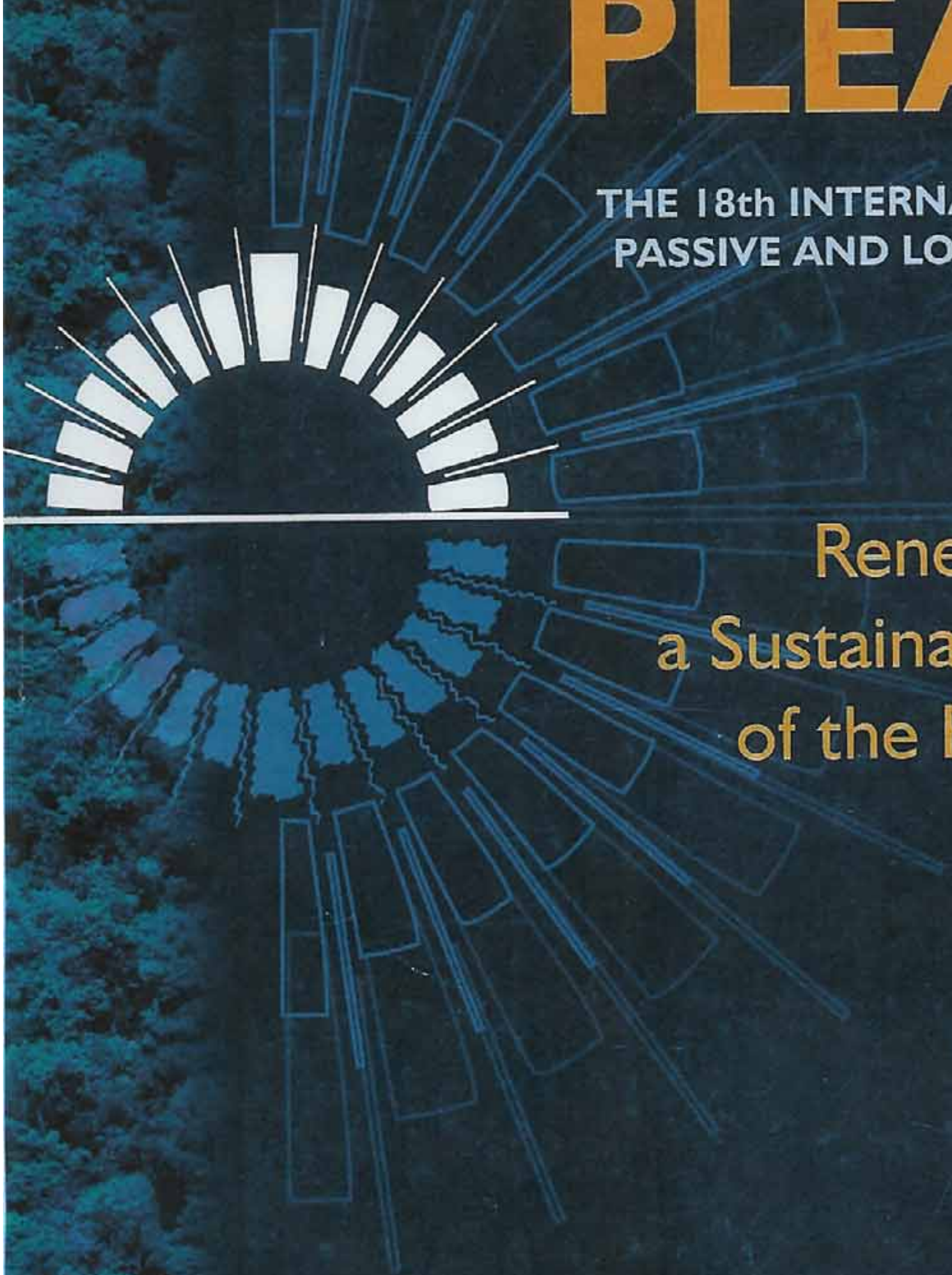

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THE *CELLULAR METHOD* TO DESIGN ENERGY EFFICIENT SHADING FORM TO ACCOMMODATE THE DYNAMIC CHARACTERISTICS OF CLIMATE

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ABSTRACT: The *cellular method,©* developed by the author, utilizes an innovative approach to determine the optimal shading form for a given period that would yield maximum energy efficiency. The method examines numerous cells, located on a proposed exterior shading plane, for their periodic shading necessity. The overall periodic shading necessity of all cells reveals an optimal shading necessity pattern which in turn provides maximum energy conservation in mechanical systems while thermal and visual comfort are maintained. In addition, by examining different shading planes for a given period, the method can provide an optimal three-dimensional shading necessity pattern. In contrast to previous methods of defining shading form, where moderate calculations are often utilized, this method takes advantage of the capabilities of today's computers. By extensive hourly examinations of numerous cells, considering different parameters determined by the user, the method provides much finer resolution of shading necessity patterns. Such patterns indicate more accurate shading forms which can optimize building energy conservation.
Conference topic: 3.2 Modeling and Simulation

1. INTRODUCTION

The awareness of the consequences of increasing energy consumption was heightened following the oil crisis in 1973 [1]. Today, world sustainability is not certain any more [2]. This phenomena is more critical because only small number of the worlds nations are responsible for most global energy consumption and pollution production [3]. The others, developing nations with vast growing populations, desire to attain similar living standards. Therefore, "*It is universally clear that we cannot go on consuming our world the way we are doing [2]".*

A partial solution for the increasing energy crisis and the decreasing quality of indoor environments is to expand the use of renewable energy sources. In the building sector, responsible for about fifty percent of the global energy consumption [2], renewable energy sources can be utilized to make buildings more energy efficient. This can be accomplished by utilizing technologies that work with the environment rather than consumptive technologies to master it [3].

The significance of exterior shading for building energy efficiency has been asserted for an extensive period. Exterior shading intercepts undesirable solar radiation before it strikes the fenestration, reflecting and dissipating it back to the atmosphere [4] [5]. As a result, it prevents from a surplus of transmitted radiation which can overheat the interior space, increasing the use of valuable energy to operate mechanical systems. Furthermore, the increased usage of large areas of high transmittance glass (often a valuable architectural feature) significantly increases the benefits of utilizing exterior shades to reduce undesirable summer solar penetration [6].

On the other hand, fixed shades reduce desirable winter solar gain and indoor daylight level, consequently increasing heating and artificial lighting loads. The optimal shading form, therefore, is a form providing optimal balance among the necessity for solar protection, solar gain, and daylighting.

In order to determine the optimal energy balance, the following parameters need to be considered: solar intensities and angles [4] [7]; dependence of glass transmittance on solar angle [8]; orientations, latitudes and climates [7]; urban or natural obstructions [8]; thermal and visual comfort [9]; daylighting [10] [9]; and occupant schedule and activities [11].

Although the importance of considering numerous aspects in the design of the optimal shade form has been pointed out and extended research has been conducted to develop better windowpanes, only limited research has been carried out to develop a holistic method accommodating these considerations.

Determination of shading device geometry has been accomplished in the last few decades, generally using a graphical method presented by Olgyay [4] [7] which utilizes sun-path and shading mask diagrams. However, this graphical method generates shading devices of rectangular shapes that usually result in excess of shading. Further efforts to provide more accurate optimal shading forms were made by Etzion (1985) [12] utilizing *one point method* for shading rectangular windows for a certain moment and Saleh (1988) [5] utilizing a graphical shading template. More recently, McCluney, (1990) [13] and Grau and Johnsen, (1995) [14] provided computerized methods to evaluate shading device performance. Indirectly, it can help determine optimal shading forms.

2. THE CELLULAR METHOD

The *cellular method*,© developed by the author, can be utilized to determine the shading form for a given period that would yield maximum energy efficiency. The method examines numerous cells located on a proposed exterior shading plane for their periodic shading necessity. The overall periodic shading necessity of all cells reveals an optimal shading necessity pattern which in turn provides maximum energy conservation in mechanical systems while thermal and visual comfort are maintained. In addition, by examining different shading planes for a given period, the method can provide an optimal three-dimensional shading necessity pattern.

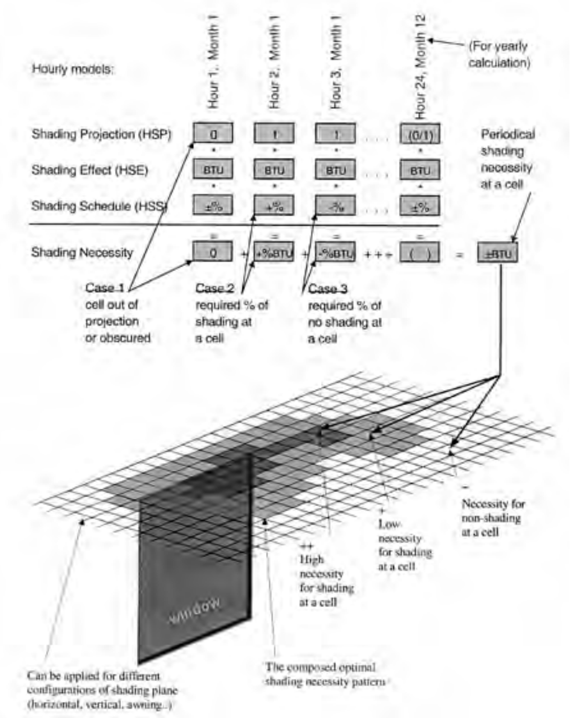

Figure 1: The Cellular Method Model.

The periodic shading necessity of a cell represents the overall relative importance of shading or non-shading during a period, providing the optimal balance among the necessity for solar protection, solar gain, and daylighting. Since heat load and daylight intensity vary according to the sun angle, the overall relative importance of shading or non-shading at a cell is calculated by summing all hourly shading necessity values included in the examined period. For instance, hours from sunrise to sunset of monthly typical days or any other periodic combination can be examined.

The *cellular method* utilizes the following three secondary models to determine the hourly shading necessity of a given cell: the Hourly Shading Projection (*HSP*) model, the Hourly Shading Effect (*HSE*) model, and the Hourly Shading Schedule (*HSS*) model (see fig.1).

2.1 The Hourly Shading Projection (*HSP*) Model

The *HSP model* conducts geometrical examination to determine if direct solar radiation reaching a fenestration (or other examined surfaces) during an examined hour is passing through a cell located on the proposed exterior shading plane. The *HSP model* assigns the value of 0 for non-passing and the value of 1 for passing.

In order to provide the data, the *HSP model* calculates the boundaries of the projected shading. The projected shading is the area within the proposed shading plane that intersects with the solar shaft during the examined hour. The solar shaft boundaries, which determine the space that sunbeams penetrating through before reaching the fenestration, are projected from all corners of the window. If the cell is located within the projected shading area, then it has a direct effect on the fenestration. On the other hand, if the cell is located out of the projected area, it does not have a significant effect on the fenestration.

In order to determine the projected shading boundaries, the *HSP model* accounts for the following parameters: fenestration configurations (shape, dimension, inclination, orientation, and the glassing recess); the dynamic position of the sun; obstruction between the sun and the fenestration; and shading plane inclination (see fig. 2).

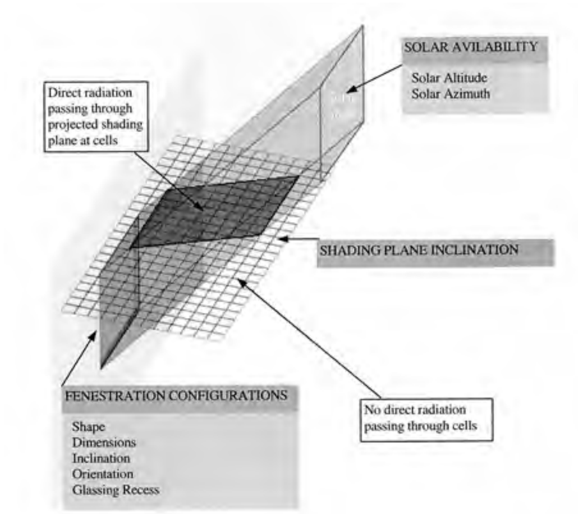

Figure 2: The Hourly Shading Projection (*HSP*) Model.

2.2 The Hourly Shading Effect (*HSE*) Model

The *HSE model* determines the amount of the potential solar radiation (Btu/f^2) during the examined hour which enters the room if non-shaded by a cell or the amount been eliminated from the room if shaded by a cell. This data accounts for the relative importance of the examined hour for the periodic energy conservation.

The *HSE model* calculates the reduction in radiation, occurring between the radiation source--the sun--and the examined space, in the following major phases: extraterrestrial radiation, atmospheric penetration, angle of incidence, and solar optical (angular dependence of transmittance); (see fig. 3).

Since the intent of the *HSE model* is to account merely for the outcome from shading by a cell, the model considers only direct solar radiation. Most diffuse radiation and ground reflected radiation which reach the fenestration are not affected by the shading cell, therefore, they are excluded from this model. Further development of the *HSE model* might account for a small portion of diffuse radiation that arrives through the cell and some of the ground reflected radiation that reflected by the cell to the fenestration.

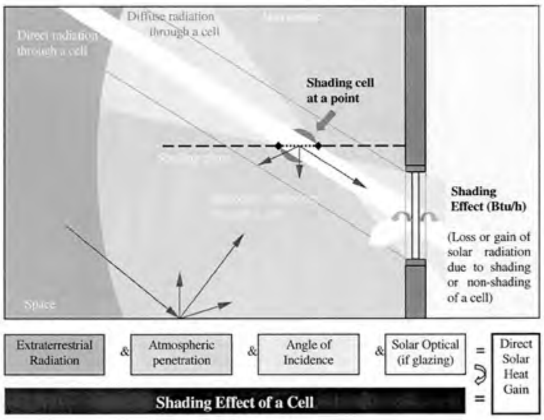

Figure 3: The Hourly Shading Effect (*HSE*) Model.

2.3 The Hourly Shading Schedule (*HSS*) Model

The *HSS model* examines the indoor thermal and visual conditions during the examined hour (accounting for a broad range of considerations) to determine if shading is beneficial or undesirable during this hour. The *HSS model* assigns to the cell a positive sign when shading is beneficial and a negative sign when shading is undesirable. The *HSS model* consists of three phases, climatic data analysis, comfort and visual assessment, and shading schedule results (see fig. 4).

In the first phase, climatic data analysis, the hourly climatic conditions are estimated from climatic data of a local weather station, considering microclimate and indoor modifications. In practice, such data can be obtained directly from several computer energy simulation programs. This phase accounts for the following broad range considerations: weather station data (temperature, humidity, air movement, and radiation); microclimate modifiers; building envelope properties; internal gain; and ventilation.

In the second phase, thermal and visual assessment, the hourly climatic conditions are examined by thermal and visual indices to determine if comfort exists at this hour, without the use of mechanical systems or artificial lighting (since the cellular method aims to conserve energy in these areas). In addition, the conditions are examined without the effect of direct radiation (since this is the element received as final result), assuming for this propose that the fenestration is fully shaded at all times. This phase also accounts for occupant activity, schedule, and clothing.

In the third phase, shading schedule results, the hourly visual and comfort results are multiplied by the following coefficients: accounting for the proportion of cooling and heating loads; accounting for the portion of solar and daylight, which is needed to be admitted to meet comfort; and accounting for the contribution of daylighting to energy conservation. The final result determines if the conditions in the indoor space require the access of solar radiation or require its exclusion.

The indoor thermal and visual conditions, at first, can be only approximated since the optimal shading form was not yet established. Once the preliminary shading necessity pattern is determined, further evaluation of the indoor conditions, including the lit portion of the window, can be conducted to refine the shading schedule. The lit portion of the window can increase the overheated period (at the second run of the model), resulting in a larger shading form. However, the increase occurs next to the comfort zone which has relatively moderate solar intensities, therefore, its effect on the shading form is approximated to be minor.

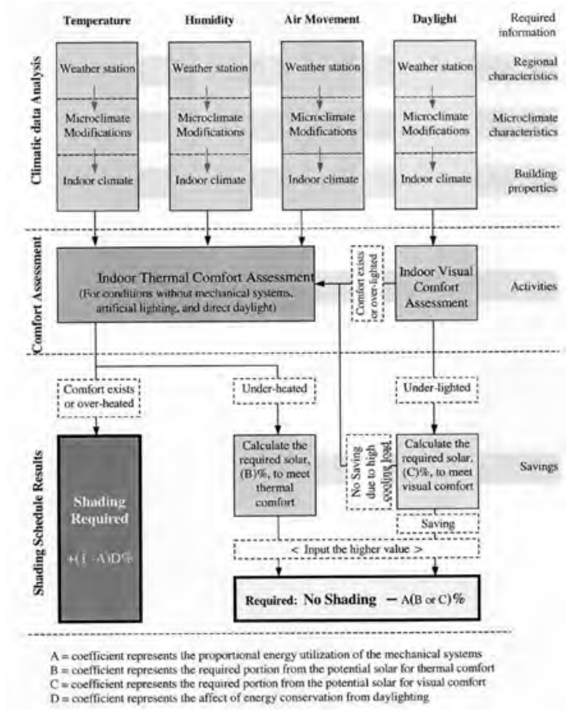

Figure 4: The Hourly Shading Schedule (*HSS*) Model.

2.4 Three Dimensional Application

The cellular method also can generate three dimensional optimal shading form by examining several shading planes of a particular fenestration. First, boundaries of desired shading form need to be determined from the shading necessity pattern of each shading plane. Then, the boundary lines located at their three dimension positions (relative to fenestration) need to be connected, generating a shading necessity surface. This surface represents an optimal three dimensional shading necessity pattern, dividing between space that requires shading and space that requires non-shading. Application of this method, the boundaries of an optimal three dimensional shading form, can be established by intersecting desirable shading form (esthetically, structurally..) with the optimal shading necessity surface (determined by the cellular method); (see fig. 5).

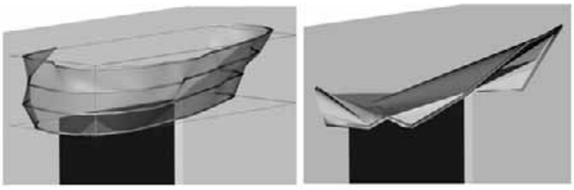

Figure 5: Three Dimensional Applications (Tucson-South).

3. METHOD ILLUSTRATION

In order to demonstrate some of the Cellular method capabilities, a calculating tool, the *Optimal Shading Form* (*OS-FORM)*, was developed by the author utilizing Excel spreadsheets. The *OS-FORM,* at this point, is capable of about 800,000 calculations to determine the periodical optimal shading necessity pattern for horizontal and inclined shading planes which shade rectangular windows. The *OS-FORM* accounts for about 15 parameters along with numerous building envelope parameters (defined in the external simulations program which provides data of indoor thermal conditions). At this point, the *OS-FORM* accounts only for thermal comfort (excluding visual comfort); it does not yet account for solar obstructions and does not yet refine the shading schedule results with the different coefficients. Future development in these areas is expected.

The following maps provide the shading necessity pattern for different windows, an example of using the *OS-FORM*. Figure 6 includes a map which provides the annually optimal shading necessity for south facing fenestration in Tucson, Arizona, considering the following prime assumptions: vertical window (8'/6'), horizontal shading plane located immediate above window, and indoor office space. Figure 7 provides the annually optimal shading necessity for west facing fenestration in Tucson, Arizona, considering the same assumptions as figure 6.

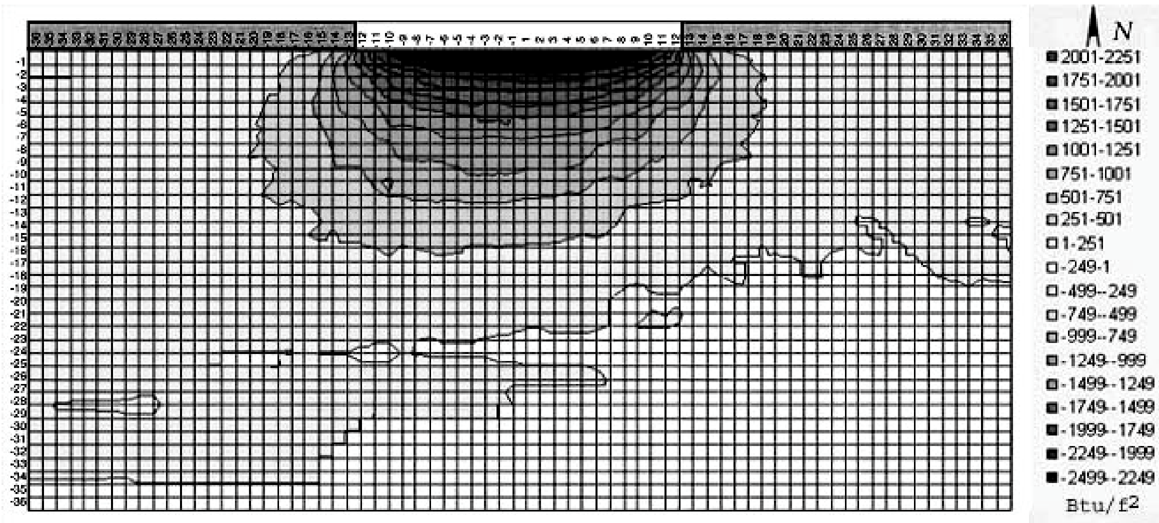

Figure 6: The annual shading necessity for south facing fenestration in Tucson, Arizona.

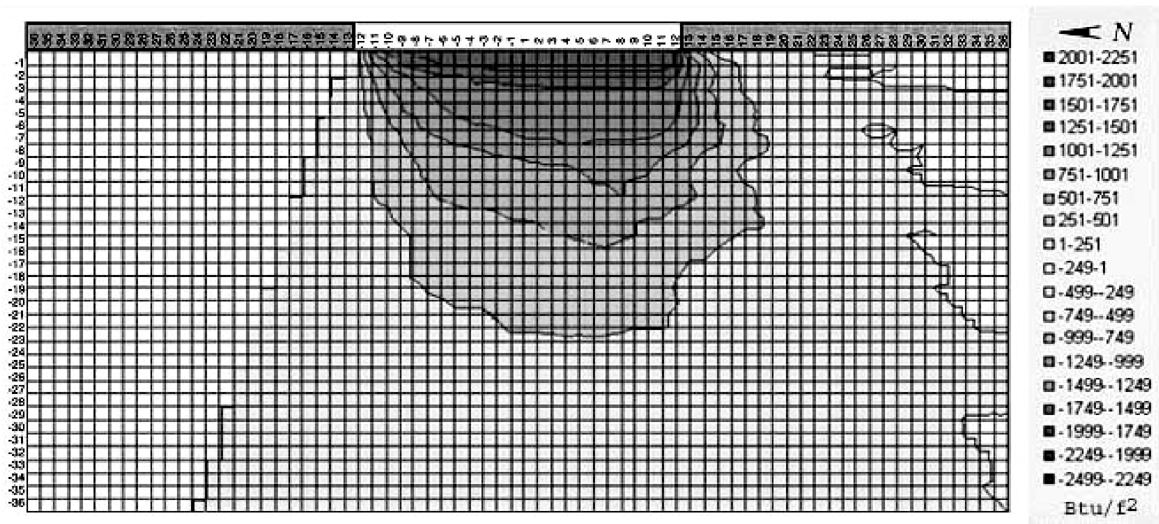

Figure 7: The annual shading necessity for west facing fenestration in Tucson, Arizona.

4. CONCLUSIONS

In contrast to previous methods of defining shading forms where moderate calculations often have been utilized, this method takes advantage of the capabilities of today's computers. The method provides much finer resolution of shading necessity patterns by extensive hourly examinations of numerous cells, considering different parameters determined by the user. Such patterns indicate more accurate shading forms which can optimize building energy conservation. Since heat loads and daylight intensities vary according to different sun angles, even a rectangular window will not have an optimal shading form with simple geometry.

The *cellular method* can provide the optimal shading necessity pattern for broad building configurations, orientations, and locations around the world where climatic data is available. It accommodates the following prime considerations: regional, seasonal, and diurnal variation in solar radiation, including azimuth, altitude, intensity and spectrum; regional, seasonal, and diurnal climatic conditions; indoor thermal and visual conditions; fenestration properties, including angular dependent solar transmittance, orientation, and inclination; thermal and visual comfort depended on occupant physiology, schedule, and activities; daylighting energy conservation; and optimal view through fenestration. Future work on method, improvement, extension, validation, and application is underway.

The *cellular method* is especially important for shading fenestration; it can also be utilized, with some adjustments, to provide optimal shading forms for shading other building components or outdoor spaces. By utilizing the *cellular method* three dimensional application, architects and planners can design future building forms which provide optimal self shading to further support building energy conservation.

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