PERFORMANCE EVALUATION OF A CLIMATE RESPONSIVE STATIC SUNSHADE USING EXPERIMENTATION

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ABSTRACT

Windows, which play a vital role for direct solar entry inside the passive solar buildings, should be properly shaded for the comfort conditioning. The present paper aims at the evaluating the performance of climate responsive static sunshade whose geometrical design is based on solar angles for the two specific dates of varying seasons over a place. The performance of five small-scale experimental models of varying aspect ratios and sunshades has been evaluated over a complete year. Depending upon the solar intersection over south facade wall, sunlit area has been correlated with temperature inside the models and made criteria to decide the effectiveness of the proposed sunshade.

Keywords: climate responsive static sunshade, small-scale experimental models, sunlit area, shaded area

1. INTRODUCTION

The main design parameters, which significantly alter the solar contribution to the total cooling and heating load inside the building, are wall areas facing the sun, ratio of window to wall area and the provision for proper sunshades. Beam radiation, which penetrates inside the buildings through various openings, can be controlled using sunshades for the temperature regulation (Yener [1]). The time dependent efficiency value of the sunshade is a geometric variable, which depends on the shading device opening system, geometry, sun position, wall orientation, etc. An ideal sunshade is expected to exclude solar radiation during over-heated periods and admit it during under-heated periods. This can be directly achieved through the use of movable or adjustable sunshades. However, these require special attention. Moreover, they are usually not considered as architectural elements; but they may be retrofitted to any building. On the other hand the required selectivity may also be realized, to a certain extent, through the incorporation of fixed sunshades. The external static sunshades intercept the solar radiation before it enters the building, and hence are most effective in solar control, must be properly designed taking into account the variations of solar positions throughout the year. The design principle of external inclined louvers for glazed openings in relation to different building facades for solar control was discussed by Chandra [2] for the annual overheated period. A practical tool was designed by Jorge et al. [3] for sizing optimal sunshades, whose performance can be evaluated using either shading mask graphical approach (El-Refaie [4], Etzion [5]) or mathematical efficiency approach (Kabre [6]) or by software approach like TRANSHD (Hiller [7]). These approaches were applied to very basic types of sunshades like horizontal or vertical one. Thus, the effective design of external shading devices is a technical problem, which should take into account the diurnal and the annual variations of solar positions and the orientation of the building elements to be shaded. For the specific design of sunshades, it is necessary to study the path traced by the sun in a day at different periods of the year.

In the present paper, the considered location (India) for the experimentation falls in Northern hemisphere under tropical climate. In Northern hemisphere, from the orientation point of view, a south

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facade has the advantage of receiving much larger solar radiation during winter than that during summer. For the openings on south facade, proper sunshade can cut-off direct solar penetration during summer and allow it during winter. Tropical climate is characterized by significant hourly and large diurnal variations in the temperatures and sunshine. It also varies considerably over the year. Large part of India that lies in tropical zone is broadly classified into six climatic zones (Parishwad [8]). For a particular location, using small-scale modeling technique (Grimmer [9]) the experimentation has been carried out for five different models with varying aspect ratios of windows and sunshades. Depending on the regulation of sunlit entry, in turn temperature inside the models the effectiveness of climate responsive static sunshade is determined over the horizontal sunshade.

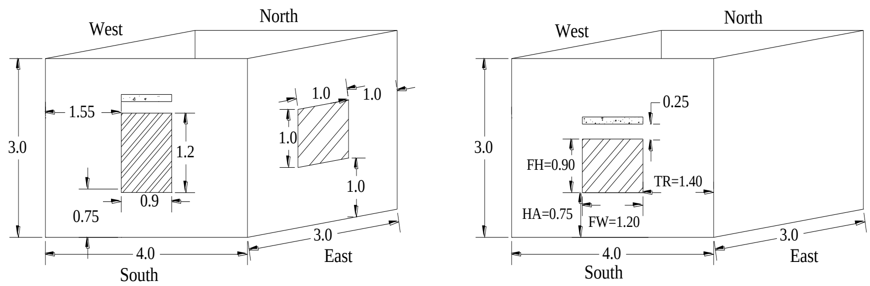
2. MODEL DESCRIPTION

The experimentation has been carried out at Birla Institute of Technology and Science (BITS), Pilani, Rajasthan (India) that lies in hot and dry zone, which has been further classified mainly under summer and winter seasons. To avoid the shading problem, constructed models have been kept apart from tall buildings. Five experimental models have been constructed of the material comprising properties as shown in Table 1 (Rohsenow and Harnett, [10]) with varying aspect ratio for south facade window and sunshades.

Small-scale modeling technique has been used in order to simulate a full-sized passive solar building using proposed sunshade for a south faced window. All the dimensions are chosen as per the actual room size as mentioned in SP: 41 [11] and later scaled down for the experimentation in proportion. Figure 1 and Table 2 indicate the detailing of model dimensions.

Table 1: Construction material properties

Sr. No.	Property / Material	Density (kg/m^3)	Thermal Conductivity (W/m. °K)	Specific Heat (kJ/Kg. °K)
1.	Brick	1820	0.811	0.88
2.	Cement	1762	0.721	0.84



M-2 M-3

Note: All dimensions are in m.

Figure 1: Model room

The model room is a rectangle parallelipipedic enclosure with a single south oriented window. All the models have same dimensions with different aspect ratio of windows and type of sunshades. Although the Models M-1, M-2 and M-5 are having same aspect ratio for the south facade window, M-1 is without sunshade, and M2 and M5 are with horizontal and proposed sunshade respectively. Models M-3 and M-4 are having reverse aspect ratio as that of M-1, M-2 and M-5. Over the window of the models M-3 and M-4 the horizontal and proposed sunshades have been constructed respectively.

Detailed methodology for deciding desired geometric shape and dimensions of climate responsive static sunshade for the considered geographic location has been described. Depending upon solar position, instantaneous measurements of the sunlit area on the internal surfaces and windowsill, shadow areas over south facade wall and temperature records of the room have been measured every hour in solar time for complete one year. From solar chart for the corresponding latitude, shading mask diagrams have been plotted. Correlated temperature findings throughout the year helps to infer that the desired projection for a horizontal sunshade may satisfy shading needs partially. Whereas, the proposed climate responsive static sunshade whose geometry is designed by calculating solar angles for the two design dates, which depends on seasonal characteristics, has been found effective as compared to horizontal sunshade for an energy efficient window. Aspect ratio comparison helps to infer that for the considered location, the window having larger horizontal dimension and lesser vertical dimension in more effective as compared to the window having reverse dimension.

Table 2: Dimensions of the Model Room

Model	Model 1(M-1)	Model 2(M-2)	Model 3 (M-3)	Model 4 (M-4)	Model 5(M-5)
Window Width FW (m.)	0.90	0.90	1.20	1.20	0.90
Window Height FH (m.)	1.20	1.20	0.90	0.90	1.20
Distance HA (m.)	0.75	0.75	0.75	0.75	0.75
Distance TR (m.)	1.55	1.55	1.40	1.40	1.55
Sunshade Type	-	H	H	P	P
Sunshade Projection (m.)	-	0.50	0.50	0.50	0.50
Model M-1: Without sunshade, H: Horizontal Sunshade, P: Proposed Sunshade					

3. SOLAR ANGLES AND DEVELOPMENT OF STATIC SUNSHADE

The sun's position in the sky changes from day to day and hour to hour. It is common knowledge that the sun is higher in the sky in summer than in winter, and that the sun rises south of east in winter and north of east in summer. In order to plan for the most effective use of shading, the sun's position must be defined. The sun's position in the sky is defined by two angular measurements: solar altitude (α) and solar azimuth (β). Solar altitude is measured up from the horizontal; solar azimuth is measured from true south.

The calculation depends upon three variables (Kreith [12]): latitude (L), declination (δ), and hour angle (H). Latitude can be read from any standard map. Declination, a measure of how far north or south of the equator the sun has moved, varies from month to month. Solar time is based on solar noon when the sun is highest in the sky.

The hour angle depends on local solar time:

$$H = 0.25 \times (m) \qquad (1)$$

Where, m= Number of minutes from local solar noon.

Knowing latitude, declination and hour angle, the solar altitude and azimuth angles are computed as:

$$\alpha = \cos L \cos \delta \cos H + \sin L \sin \delta \tag{2}$$

$$\beta = \cos \delta \sin H / \cos \alpha \tag{3}$$

For the shading calculations profile angle (γ) is computed. It is defined as the angle between the normal to a surface and the projection of the sun's rays on a plane normal to the same surface. It is used in sizing shading devices, and is given by

$$\tan \gamma = \sec a \times \tan \alpha \tag{4}$$

Where, a = Wall normal-to-solar azimuth angle or horizontal shadow angle

With the help of above-mentioned equations (1-4), one can compute the required solar angles on any particular day at any desired time. Alternative approach to determine the same is to use solar chart. The shadow angle protractor can be used to compute desired shading over a particular duration. Stepwise methodology for the static sunshade development is as follows:

- With the given orientation of the facade for which a static sunshade is to be designed, a decision as to the design day and the period of time on that design day during which the window is to be shaded is made.
- The corresponding vertical and horizontal shadow angles at a close interval of time for accurate geometry of desired static sunshade, which defines the movement of sun relative to a normal projection from the face of the facade is computed.
- A decision about the maximum projections of the static sunshade from the face of the building and also on its extension beyond each side and above the window is made.
- Then the sun's movement relative to building facade and window position to obtain the desired geometry of static sunshade is plotted.

Thus, using horizontal shadow angles, the sun's position relative to the normal for the wall is plotted in the plan. The sun's morning and afternoon movement is plotted from the western-most lower edge and eastern-most lower edge of the window. The obtained intersection points in plan are projected in side-view with the vertical shadow angles from lower edge of the window. These points are then projected onto the elevation. The most important part is the practical design of the obtained geometry of sunshade.

4. DESIGN DEVELOPMENT OF PROPOSED STATIC SUNSHADE

For the considered location (Pilani, Rajasthan, India) geographical details are as Latitude: 28.25°N Longitude: 75.65°E. Studying the atmospheric data from previous years it has been inferred that the climatic condition over the region is extreme. With reference to solar chart (Duffie et al. [13]) and comfort temperature zone (18-27°C) the design dates have been chosen for the development of proposed climate responsive static sunshade. 22nd December, where the sun is at lowest position in the sky as well from climatic point of view, which lies in extreme winter, should allow full entry of sun through the window, is chosen as first design date. Similarly 23rd March (equinox), where the sun is appreciably at higher heights in the sky, is chosen as the second cutoff date. From the climatic point of view, the second cutoff date lies, where the season changes from comfort to summer after which there should be no direct entry of sun inside the model. Assumption made for the design development of static sunshade is that sun entry will be between 8 a.m. to 4 p.m. solar time from south facade window inside the model. Using the described methodology the proposed geometry of the static sunshade for the considered dates has been obtained as shown in Figure 2. Considering the problem of accumulation of rainwater at the interface between sunshade and wall surface, minimum amount of drop-down is made at the end of the sunshade. The surface is generated using Ferro-cement (Reinhold [14]). The actual constructed models have been shown in Figure 3.

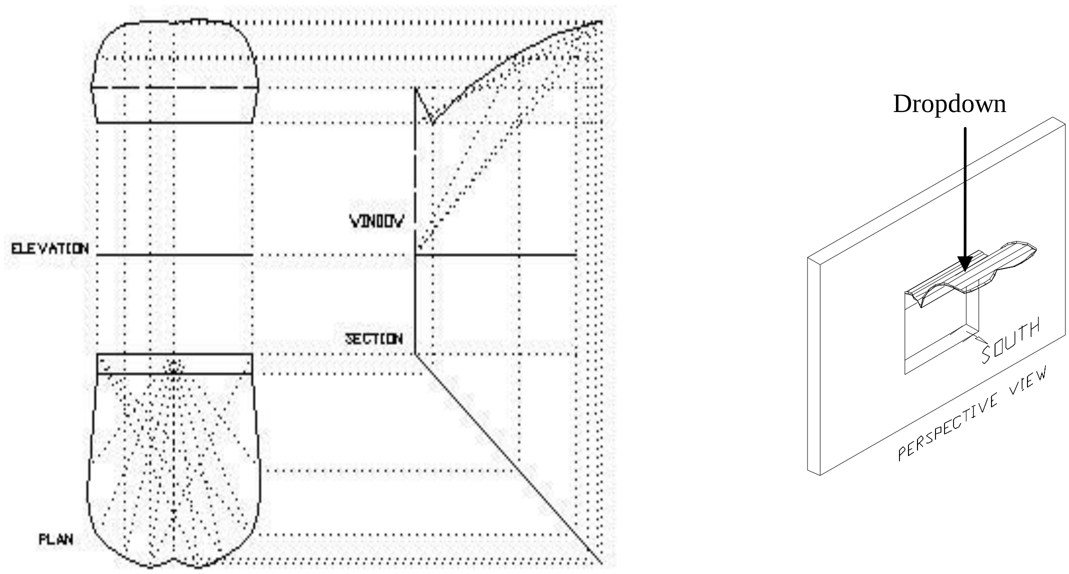


Figure 2: Plan, Section, Elevation and Perspective View of Proposed Static Sunshade

5. RESULTS AND DISCUSSION

Keeping in view the window and sunshades over the south facade wall, various modes of solar intersection i.e. either sunlit area through the window or sunlit windowsill area have been measured depending upon the solar position. Corresponding temperatures have been recorded in the constructed models. During several months of summer, due to high solar position in the sky sunlit areas have been recorded negligible, therefore the shadow over the south facade wall have been measured and correlated with the temperature findings inside the models. The various values were recorded throughout the year during sunlight hours through various days. Different graphs represent timely variation of the measured sunlit area or shadow area and temperature inside the models between 8 a. m. to 4 p.m.

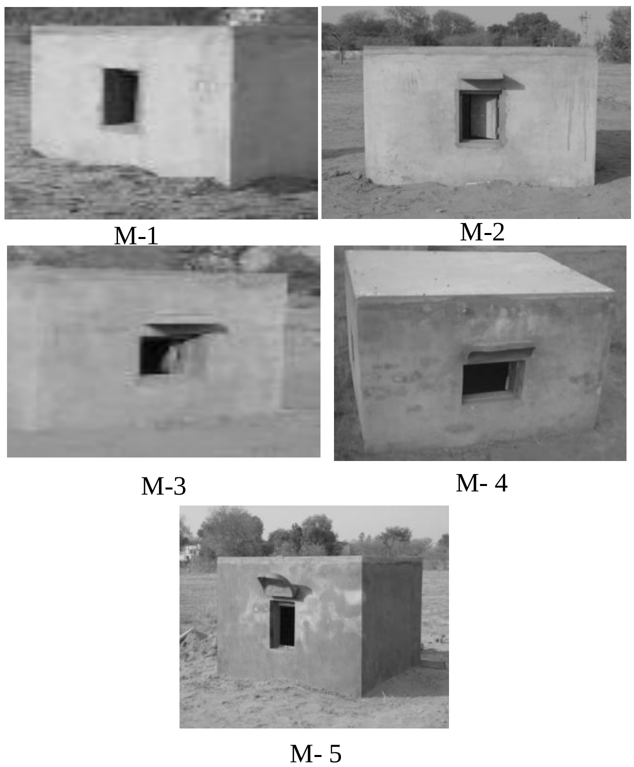


Figure 3: Actual constructed small-scale models

Keeping in view the sunlit entry inside the models from the recorded data, the average day of January has been represented for the understanding of analysis methodology. The important findings are shown in Figure 4. It represents the various sunlit area records (Figure 4a) for all the five models along with variation of temperature findings (Figure 4b) inside the model throughout the day.The area under sunlit area curve has been made decision criteria to decide the effectiveness of static sunshades. Fourth order equation has been found suitable with the trend obtained for the curves as shown in Figure 4a. Using Simpson's rule for integration (Allison [15]) area under the sunlit area curve was calculated.

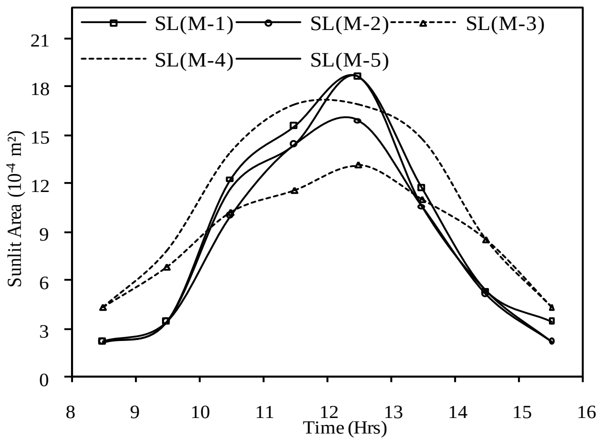


Figure 4 a: Sunlit Area on average day (22) of January

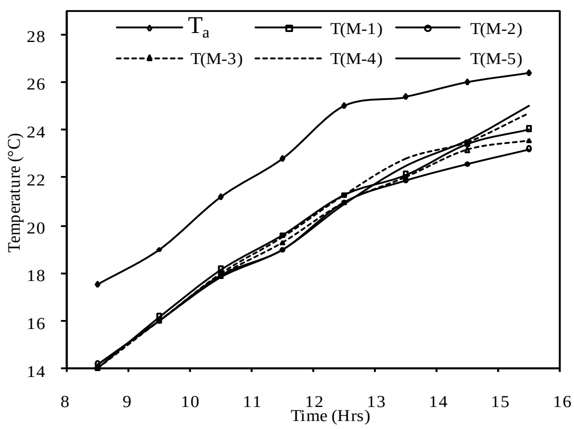


Figure 4 b: Temperature on average day (22) of January

Table 3 represents total area under sunlit area curve, which helps to determine the shading characteristics under all models. From the temperature curve as shown in Figure 4b, it can be observed that the ambient temperature for the considered case is nearly under comfort zone (18-27°C) and hence there should be ample amount of direct entry of sun inside the models. Thus, performance-wise one can rate the Models in ascending order as M-4, M-1, M-5, M-3 and M-2 respectively. The average temperature gain inside a model is proportional to effective sunlit area inside the model as presented in Table 3. To study the overall effectiveness over the window dimensions and sunshade type detailed analysis has been carried out further.

Table 3: Area under the sunlit area curves on 22-January

Model	Equation	Area (10^{-4} m^2)	Average Temperature (°C)
M-1	$Y = 0.1524X^4 - 2.7569X^3 + 15.594X^2 - 28.034X + 17.1$	68.91	19.86
M-2	$Y = 0.1238X^4 - 2.2724X^3 + 13.005X^2 - 23.592X + 14.838$	60.68	19.46
M-3	$Y = 0.0186X^4 - 0.383X^3 + 2.006X^2 - 0.9619X + 3.5354$	66.14	19.63
M-4	$Y = 0.0624X^4 - 1.1459X^3 + 6.0203X^2 - 7.0238X + 6.257$	83.98	19.99
M-5	$Y = 0.14X^4 - 2.5576X^3 + 14.571X^2 - 26.334X + 16.268$	68.82	19.83

From the measured values if maximum and minimum values are observed for the temperature as shown in Figure 5, the entire region has been classified into the seasonal classification as shown in Table 4. The months have been classified as per the average dates. Depending upon the solar positions, various area values have been measured throughout the year. Sunlit areas have been recorded inside all the five models over a period from December-March and September-December. Similarly, windowsill areas have been recorded in all the five models over a period from April-May and August-September. During May-July although windowsill area recording have been continued in the Model M-1, for all the other Models M-2, M-3, M-4, M5 shadow area over south facade wall due to sunshade have been recorded.

Using the above mentioned integration approach to determine area under either sunlit area or windowsill area or shadow area curves; overall effect has been analyzed as represented in Figure 6. As represented in Figure 6 with respect to sunlit entry inside the model, all the five models can be tabulated in ascending order are summarized in Table 5, which gives clear picture of solar entry inside the models. Keeping in view the control of solar entry inside the models and seasonal classification the best suitable model has been categorized individually.

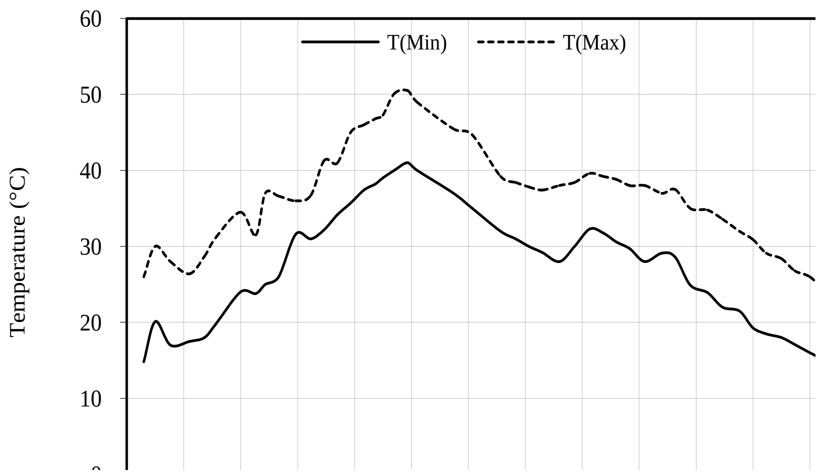


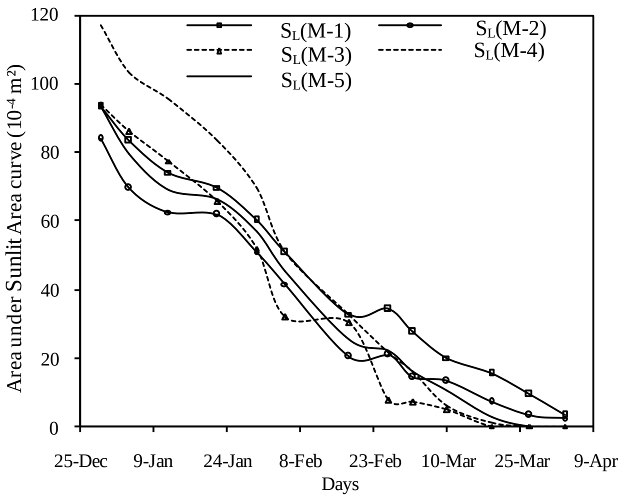
Figure 5: Yearly temperature variation

The overall shading characteristics for different models having specific sunshade has been shown in Figure 7 with the help of shading mask diagram. As represented in Table 5, the model which is placed at position one implies maximum entry of sunlit, whereas the model which is at fifth position implies maximum restriction for sunlit. All the other intermediate performance models are placed sequentially in between. The relations shown with the equal sign imply that the overall area measured is same for those particular models. As per the sequence shown in Table 5 it is very clear that the design criteria considered for the proposed static sunshade model has also been satisfied experimentally. The Models M-4 and M-5 are having better exposure in peak winter later reducing during overheated period. As shown in Table 5, with respect to sunlit area regulation inside the models, Model M-4 has been found suitable over most of the considered dates of various months throughout the day. As per the considered seasonal classification Model M-4 is representing best performance over the solar entry regulation followed by model M-5. Model M-3 followed by M-2 has been rated as an intermediate option for selection of sunshade; whereas Model M-1 that is not protected with any type of sunshade should not be recommended.

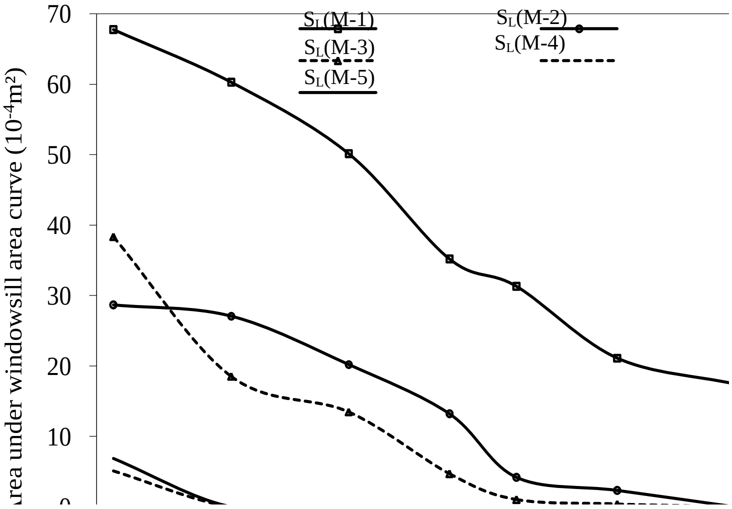
As per seasonal classification represented in Table 4 and the model exposure characteristics as summarized in Table 5 it is observed that the temperature variation is also of similar nature inside the models. Thus, the exposure to sun and temperature variation inside the models are directly proportional [Figure 4]. The temperature variation during peak winter is not significant in all the models due to low radiation intensity, which is seen prominently during over heated period. It is very clear from the Figure 6 and 7 that the model M-4 with proposed climate responsive sunshade is giving best control over solar penetration inside the model in turn temperature followed by Model M-5, M-3, M-2 and M-1 respectively.

Table 4: Seasonal classification

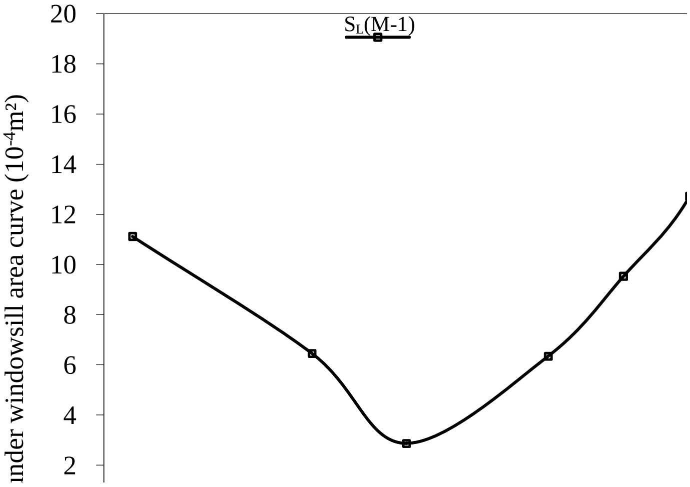
Month	Seasonal Classification
December	Winter
November, January	Comfort
February, March, September, October	Moderate (Maximum: Discomfort)
April, May, June, July, August	Summer



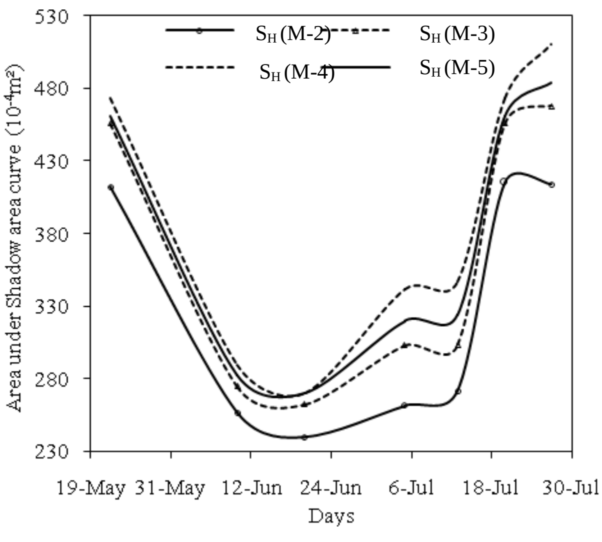
6.1


70
60
50
40
30
20
10
S_L(M-1)
S_L(M-3)
S_L(M-5)
S_L(M-2)
S_L(M-4)
rea under windowsill area curve ($10^{-4}m^2$)

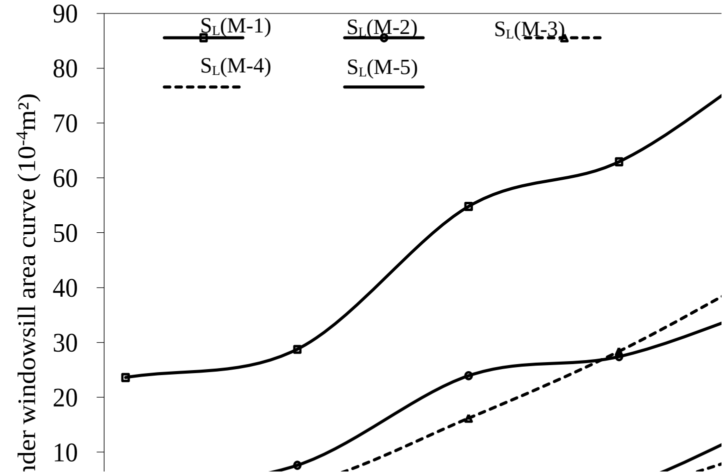
6.2


20
18
16
14
12
10
8
6
4
2
S_L(M-1)
nder windowsill area curve ($10^{-4}m^2$)

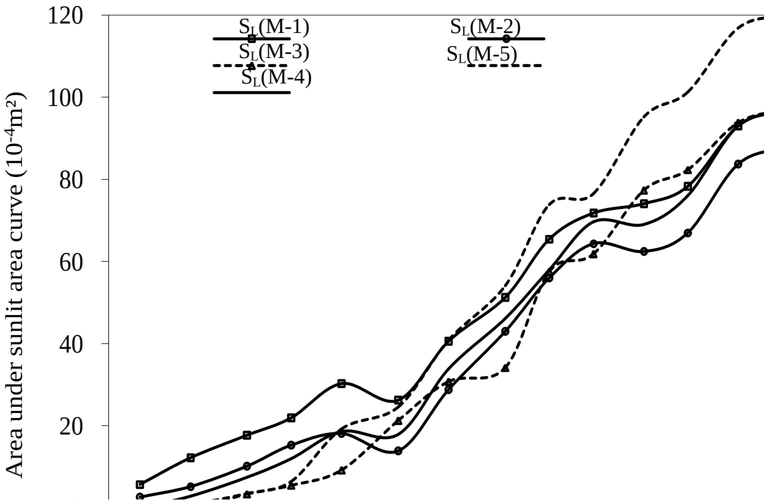
6.3


530
480
430
380
330
280
230
S_H(M-2)
S_H(M-3)
S_H(M-4)
S_H(M-5)
Area under Shadow area curve ($10^{-4}m^2$)
19-May
31-May
12-Jun
24-Jun
6-Jul
18-Jul
30-Jul
Days

6.4



6.5



6.6

Figure 6: Overall measured areas for the models

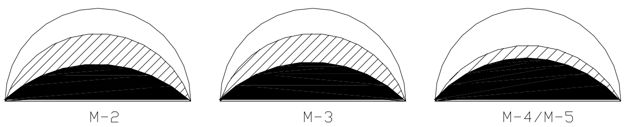


Figure 7: Shading mask diagram

6. CONCLUSIONS

The experimental study over a year rightly points the importance of proper window dimension over south facade wall, as well importance of proper use of static sun shade for energy regulation inside the buildings. The proposed climate responsive sunshade has been developed using sun path diagram and shadow angles for desired cutoff dates. The performance evaluation study presented in the paper helps to analyze that the regulation of sunlit area inside the model with the proposed sunshade is more effective as per considered seasonal requirements, which in turn regulates temperature inside the model and hence useful for energy conservation inside the buildings. Thus, the methodology helps to predict desired aspect ratio for energy efficient windows as well suitability of static sunshade. Similar models can be implemented for practical purposes in large passive solar architecture buildings, which help to reduce heating as well as cooling requirements inside the buildings

Table 5: Model performance as per overall measured areas

Months	Model order as per sunlit entry inside the model	Best Suited model
December (Last week) – January (Mid week)	***M-4***, M-3, M-1=***M-5***, M-2	M-4
January (Third week, Last week)	***M-4***, M-1, ***M-5***, M-3, M-2	M-4
February (First week)	M-1=***M-4***, ***M-5***, M-2, M-3	M1, M-4
February (Third week)	M-1=***M-4***, M-3, ***M-5***, M-2	M-5
February (Last week)	M-1, M-2= ***M-4=M-5***, M-3	M-4, M-5
March (First week)	M-1, ***M-4=M-5***, M-2, M-3	M-4, M-5
March (Second week, Third week)	M-1, M-2, ***M-5=M-4***, M-3	M-4, M-5
March (Last week) - April (First week)	M-1, M-2,M-3=***M-4=M-5***	M-4, M-5
April (Second week)	M-1, M-3, M-2, ***M-4=M-5***	M-4, M-5
April (Third week) - May (Third week)	M-1, M-2, M-3, ***M-4=M-5***	M-4, M-5
May (Last week) – July (Last week)	M-1, M-2, M-3, ***M-5, M-4***	M-4
August (First week) – September (Second week)	M-1, M-2, M-3, ***M-4=M-5***	M-4, M-5
September (Third week) – October (First week)	M-1, M-2, ***M-5, M-4***, M-3	M-3
October (Second week)	M-1, ***M-4, M-5***, M-2, M-3	M-5
October (Third week)	M-1, ***M-4***, M-3, ***M-5***, M-2	M-5
October (Last week)	***M-4***, M-1, ***M-5***, M-3, M-2	M-5
November (First week)	***M-4***, M-1, ***M-5***, M-2, M-3	M-4
November (Second week)	***M-4***, M-1, ***M-5***, M-3, M-2	M-4
November (Third week)	**M-4**, M-1, **M-5**, M-2, M-3	M-4
November (Last week) - December (Third week)	***M-4***, M-3, M-1, ***M-5***, M-2	M-4
Note:** ***Bold letters indicates ordering of the models with proposed sunshade		

NOMENCLATURE

FH- Window Height
FW- Window Width
HA- Sill Height
L- Latitude
S_{L}- Area under sunlit area curve
S_{I} - Area under windowsill area curve
S_{H} - Area under shadow over south facade wall area curve
T- Temperature inside the models
T_{A} - Ambient Temperature
T_{R} - Distance between side wall and window Jamb
β- Solar azimuth
δ- Declination
γ- Profile angle

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