OPTIMUM SHADING DESIGN IN BUILDING INTEGRATED PHOTOVOLTAIC OVERHANG

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ABSTRACT:
The study analyses the performance of thin film Building Integrated Photo Voltaic (BIPV) overhang with different projection factors and orientation and its corresponding effect on PV energy yield, indoor day lighting and air conditioning energy requirements in a modeled building which is compliant to Energy Conservation Building Code (ECBC) and located in warm and humid climatic zone (Chennai). The PV overhang is mounted over the South wall window with 27% window to wall ratio (WWR) and installed such that the watts/m^2 remains constant in all the considered cases. The total conditioned area of the zone under consideration is 41.04 m^2 The building model is simulated using EnergyPlus software for a total of ten cases, with five cases having horizontal orientation and varying projection factors (No overhang, Projection Factors-0.25, 0.5, 0.75 and 1) while the other five have inclined orientation equal to latitude of the location and with similar projection factors as above.
Simulation results are summarized as annual, monthly and hourly graphs. The annual graphs show the load breakup of the building for different projection factors and help to identify the general trends in variation in cooling and lighting energy consumption.

KEYWORDS: BIPV, Semi-transparent photovoltaic window, Building simulation, solar heat gain coefficient.

01. INTRODUCTION

The trend of increasing energy consumption in the building sector is closely linked to the growth in economy and deployment of technology. Thus, globally electrical energy consumption is rapidly increasing [1]. The advent of PV technology for building applications in the 1970s has grown at a fast pace and in present times BIPV systems are increasingly being incorporated into the construction of new buildings as a principal or supplementary source of electrical power [2]. There manifold use in the building envelope includes façade, roof, window glasses and window shading devices etc. The BIPV with its dual characteristics of energy generation and as a building construction component not only achieves a good aesthetics, but also promote the development of energy efficient buildings [3, 4].
In recent years, many theoretical and experimental studies have been conducted to maximize the energy benefits of BIPV systems, in terms of the power output of PV modules and the cooling/heating load reduction of buildings for which the windows plays a dominant role [5]. Appropriate designs of window size, glazing and shading device help to modulate the effect of the sun and wind on indoor environment as suited for a particular climatic zone and building topology. Exterior shading devices often work well to both reduce head gain and diffuse natural light before entering the work space. Examples of such devices include light shelves, overhangs, horizontal louvers, vertical louvers, and dynamic tracking of reflecting systems [6]. In this study, the performance of thin film BIPV overhang is analyzed for a modeled office building

The values for factors that constitute the internal loads of the building like People Density, Lighting Power Density, people activity and the set of schedules included in the model are as per Table 02.

The People Density parameter which is a peak value specifies the number of occupants per floor area and is adjusted by occupancy schedules which in this case are uniform during the office schedule. The Light Intensity parameter is 10.8 W/m^2 for a typical office building by Building Area Method as per ECBC guidelines [7]. The equipment power density is taken as 80 W/person considering general office loads like photocopier, fax machines etc. shared between occupants [8]. The average heat gained per occupant is calculated as an average for male and female occupants from the ASHRAE guidelines [9]. The illuminance set point field activates automatic dimming controls for electric lighting when natural daylight is sufficient and is set at 500 Lux. The Day lighting illuminance set point determines the target light level at a work plane located in the zone at a height of 0.8 m (2.6 ft.) above the floor. There is one Day lighting reference point which takes into account the depth of penetration of the daylight [7].

Table02. Principle Building Activity [7, 8, 9]

Parameter	Value
Lighting Power Density (W/m^2)	10.8
Lumens Level (Lux)	500
Occupancy (Number of people) Core /Other Zones	8 /6
Office Schedule	09.00amto 18.00pm
Operational Days	Weekdays except holidays
Type of HVAC	Packaged Terminal Air Conditioner (Auto sizing)
Depth of Daylight penetration	15 feet
Office Equipment (W/person) Fraction Radiant	80 0.2
People Activity (W/person) Fraction Radiant Sensible Heat Fraction	100 0.5 0.6

2.5 Fenestration Details

The designed building has one window each of dimensions 14.5mx1m on three sides stretched throughout its length except the North Wall which has two windows of dimensions 6mx1m with a door in between the windows as shown in Fig 03. The Window to Wall ratio is close to 27%.

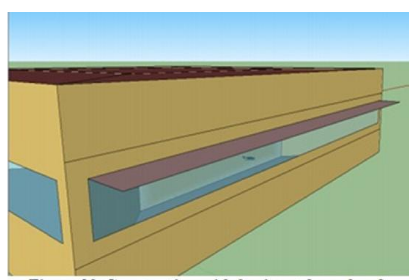


Figure 03. Construction with horizontal overhand on South window

Overhangs are defined by the Projection Factor and offset fields. Projection Factor specifies how far the overhang projects out from the wall that anchors it as a fraction of the window height while offset specifies the vertical distance from the top of the window to the overhang as a fraction of the window height. Overhangs specially in northern hemisphere are effective in modulating to an advantage the effects of solar heat and wind during summers and winters for south direction as covered in this study.

Visible Transmittance, or daylight transmittance, is the percentage of visible light passage through the glazing. Solar Heat Gain Coefficient (SHGC) expressed as a number between 0 to 1 measures how much heat from the sun is blocked. The ECBC defines projection factor which is calculated by measuring the distance from the window to the edge of the overhang and then dividing it by the distance from the bottom of the window to the lowest point of the overhang.

Projection Factor=Horizontal (H)/Vertical (V)

The ECBC provides modified SHGC requirements which is calculated for a given projection factor by dividing the SHGC for unshaded fenestration by a multiplication (M) factor. A separate M Factor is determined for each specific orientation and unique shading condition. The PF of the window is varied, which in turn changes the M-Factor of the glazing used on the window. As a rule of thumb the VLT to SHGC ratio is kept to a constant of 1.25. The maximum value of both these variables is unity.

U-values are used to measure how effective elements of a buildings fabric work as insulators. The lower the U-value of an element of a building's fabric, the more slowly heat is able to transmit through it, and so the better it performs as an insulator [10]. The detailed glazing specifications for the warm and humid climatic zones in India may be found in the Table 03 below;

Table 03 Warm and Humid Climate Glazing Specification

Chennai climatic			
Projection Factor	**VLT**	**SHGC**	**U-Factor**
Base Case	0.3125	0.25	3.3
0.25	0.400625	0.3205	3.3
0.5	0.504	0.4032	3.3
0.75	0.568125	0.4545	3.3
1	0.625	0.5	3.3

03. METHODOLOGY

The methodology of the study sequentially covers the preparation of building model, PV integration & simulation for ten cases. In that five cases for the horizontal configuration and remaining for the tilted configuration (at equal to the latitude of the location). Analysis of the simulation results on annual basis as described below.

3.1 Building Modeling

The 3D model of the building with the geometrical parameters as described above was prepared in GoogleSketchUp8 software. Thereafter, the idf file of the model was imported in EnergyPlusV-8-1-0 for simulation purposes. In EnergyPlus the building envelope materials were chosen for construction of all building elements and thereafter the building operational parameters and loads are defined for lightening load, equipment load and HVAC load for an office building.

3.1.1Concept of Projection Factor for Tilted Configuration Overhang

In order to assign projection factor a value, the horizontal and vertical component are calculated according to the assumed projection factor. The length of the overhang also tends to change with the latitude angle in consideration.

$\mathbf{tan(90-\theta)=\frac{H}{k}}$ ……… (1), Where Θ =Latitude angle for the given location.

$\mathbf{0.25=\frac{H}{1-k}}$ ……………… (2), assuming a projection factor of 0.25.

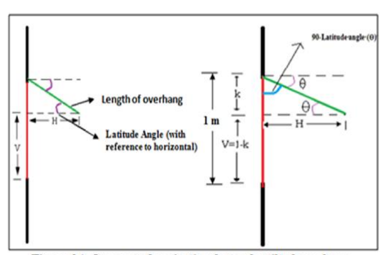


Figure 04. Concept of projection factor for tilted overhang configuration

From the above equation 1&2 the corresponding length of the overhang for a given projection factor and location can be computed. Since the values of SHGC and VLT are dependent on multiplication factor and hence projection factor, they would remain same as that in case of horizontal overhang stretched at 90° to the horizontal.

3.2 Photovoltaic Integration on the Shading Device

Photovoltaic modules are integrated on the overhangs and their current and voltages are a function of the length and breadth of the overhang.
For e.g., The Original dimensions and specifications of the thin film PV modules are; Length 1580 mm and Widths 798 mm thus the area of module is area 1.26 m^2.
The original currents and voltages of the module unit are;

$$I_{sc}=3.64\text{ A};\ I_{MPP}=3.31\text{A and } V_{oc}=65.7\text{ V};\ V_{MPP}=52.9\text{V}$$

The Dimensions of the overhang for a projection factor of 0.25 and horizontal tilt are;

Length= 14500 mm; Width= 250 mm

Thus, ten modules of dimensions 1450mmx250mm and area 0.3885 m^2 may be assumed to be mounted throughout the available overhang.
Therefore, percentage decrease in length is 8.227% and Percentage decrease in width is 68.67%. Thus, the currents and voltages of the new module unit are;

$$Isc= (1-0.6867)*3.64= 1.1403\text{ A};\quad I_{MPP}= (1-0.6867)*3.31= 1.0369\text{ A}$$

$$Voc= (1-0.08227)*65.7= 58.2151\text{ V};\ V_{MPP}= (1-0.08227)*52.9= 46.8734\text{ V}$$

By adopting this method it is ensured that watts/area of the module remains same. The same method is applied for overhangs with latitude tilt.

04. RESULTS AND DISCUSSIONS

4.1 Building performance analysis

The results obtained from whole building simulation are extracted and sorted in a way that reflects the effects of increasing the projection factor and tilt of the overhang as shown in Fig 05. The Output obtained in a Microsoft Excel format is then plotted in graphs to study the load variations with change in variables i.e. Cooling, Heating, Lighting and Equipment. Also, generation from Photovoltaic module is plotted to offset it from the total building energy consumption.

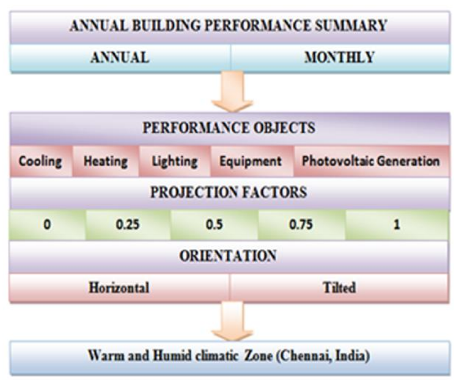


Figure 05. Input and Output Variables for Building Performance Analysis

4.2 Cause Effect Analysis

The cause effect analysis is performed by the help of output variables for heat gain windows, solar insolation and illuminance level at the day lighting reference point for the South zone. The data is sorted as shown in the Figure 06 and plotted.
The simulation results show the variation in the building loads (heating, cooling, lighting and electrical equipment) on annually, monthly and hourly basis. The

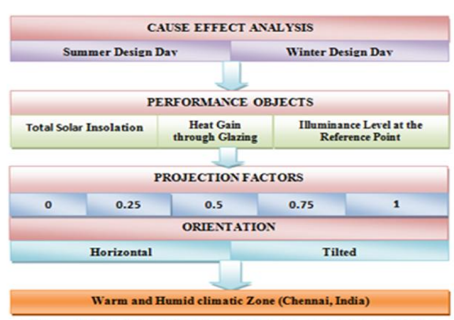


Figure 06. Input and Output Variables for Cause Effect Analysis

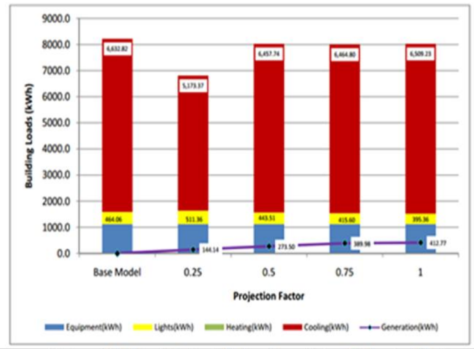
hourly data lends strength to the analysis and provide deeper insights into the causes of variations that have been analyzed in the monthly and annual results for different climatic zones and overhang sizes.

4.3. Annual Results and its Analysis (Warm and humid climatic zone, Chennai, India)

4.3.1. Horizontal Orientation

From the figure 07 it is evident that the cooling load decreases with increase in projection factor up to 0.25 beyond which it starts increasing with the increase in projection. This behavior is attributed to the increase in SHGC with increase in projection, in conformation to the ECBC recommendations. Since cooling has almost 80% share in the building load for this climate, reduction in HVAC is important for the building performance optimization.

There is a huge deviation in lighting load as well. The lighting load for PF 0.25 is the highest as increase in VLT does not completely compensate for the shading effect caused by the overhang. Lighting energy consumption shows the usual trend of reduction after PF 0.25 due to increase in VLT with increasing PF. Due to a balance between increase in cooling load and decrease in lighting load, PF 0.75 has the lowest total consumption amongst all 90° tilt cases.



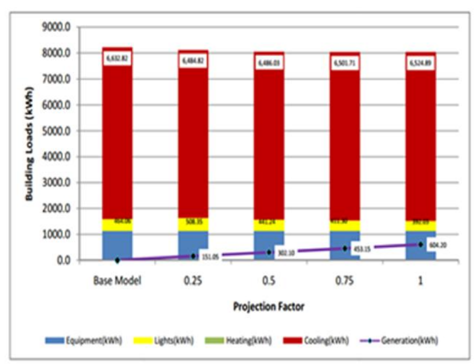
	Equipment (kWh)	Lighting (kWh)	Heating (kWh)	Cooling (kWh)	Generation (kWh)	Total Consumption (kWh)	Effective consumption (Consumption – Generation) kWh
Base Model	1123.2	464.1	0.0	6632.8	0.0	8220.1	8220.1
0.25	1123.2	511.4	0.1	5173.4	144.1	6808.0	6663.9
0.50	1123.2	443.5	0.1	6457.7	243.5	8024.6	7751.1
0.75	1123.2	415.6	0.1	6464.8	390.0	8003.7	7613.7
1	1123.2	395.4	0.1	6509.2	412.8	8027.9	7615.1

Figure 07. Power consumptions and photovoltaic generation with Horizontal overhang

4.3.2 Tilted Orientation

The tilted configuration i.e. equal to latitude of the location shows staggering results with PF 0.25 having the lowest HVAC energy consumption amongst all the nine cases of this climatic zone. It has almost 21% less cooling requirements than the base model.

The lighting load is again minimum for PF 1 due to very high VLT of the fenestration and it is slightly higher than the horizontal PF 1 configuration due to blockade in the path of solar radiations. Generation is lower for tilted orientations for the same projection factors as horizontal orientations. It is approximately 30% less than the horizontal configuration. From the above study, it is concluded that the optimum case from the perspective of both Total consumption as well Effective consumption is Tilted orientation with projection factor 0.25.



	Equipment (kWh)	Lighting (kWh)	Heating (kWh)	Cooling (kWh)	Generation (kWh)	Total Consumption (kWh)	Effective consumption (Consumption – Generation) kWh
Base Model	1123.2	464.1	0.0	6632.8	0.0	8220.1	8220.1
0.25	1123.2	508.3	0.1	6484.8	151.1	8116.4	7965.4
0.50	1123.2	441.2	0.1	6486.0	302.1	8050.6	7748.5
0.75	1123.2	411.3	0.1	6501.7	453.2	8036.3	7583.2
1	1123.2	392.0	0.1	6524.9	604.2	8040.2	7436.0

Figure 08. Power consumptions and photovoltaic generation with Tilted overhang

4.3.3 Summary of Results

The results of the Research work indicate the following findings

1. Effect on Lighting Load
2. Effect on Cooling Load
3. Effect on Heating Load
4. Photovoltaic Power Generation

1. Effect on Lighting Load

The lighting load of a climatic zone depends on seven factors namely, location of the fenestration, lux levels required, total solar insolation, length of the overhang, tilt of overhang, sun path and hour of the day. A general trend is noticed that the lighting energy for tilted orientation is more than the one at 90° tilt implying that daylight integration is negatively affected by a tilt in the shading. It is also noticed that the lighting requirement decreases as the projection factor increases. This happens due to the fact that the ECBC recommends increasing the SHGC and VLT of the fenestration in proportion to the shading above it. The recommended increase in VLT is so high that the lighting load shows contradictory behavior when overhang length is increased as shown in Figures 07 & 08.

2. Effect on Cooling Load

The cooling energy consumption decreases with increase in projection factor up to an optimum limit after which it started increasing with increase in overhang length. This increase in consumption happens due to change in fenestration properties. As mentioned in the former point, according to the ECBC guidelines, the SHGC and VLT must change to accommodate the shading effect of overhang. The shading device reduces the heat gain whereas the increase in SHGC promotes heat gain through fenestration. These two factors work in opposition to each other. As long as shading effect dominates the increase in SHGC, the cooling load reduces. As the increase in SHGC becomes dominant, the cooling load starts increasing. The supremacy of shading effect depends on the latitude of the climatic zone and tilt of the overhang. This effect is distinctively noticed in the warm and humid climatic zone where the tilted overhang with PF 0.25 has the lowest cooling load and the difference between maximum and minimum cooling load is very high. Tilted overhangs, in general, have a lower cooling energy requirement as compared to the 90° tilt overhangs as shown in figure 07 & 08.

3. Effect on Heating Load

The heating load depends on weather of the zone, its latitude i.e. sun path, fenestration properties, shading device's length, building orientation and relative position of the wall, properties of the building envelop, building activity and site ground temperature. It is noticed from the results that the heating load increases with increase in length due to the fact that solar heat ingress is blocked by shading. The effect of increase in SHGC is minimalistic as the solar insolation is not as high as in other climatic zones and summer months.

In warm and humid climate, heating is a small part of building load as compared to the cooling load, thus, reduction in cooling load is more important. Thus despite a negative effect on heating load, mounting of overhang is recommended.

The building with no overhang allows maximum solar heat gain in the building; it is found to be the optimum case amongst all other cases and has the least total energy consumption.

4. Photovoltaic Power Generation

The PV generation mainly depends on the solar insolation, module temperature and PF. For warm and humid climatic zone energy yield is good due to high insolation, low surrounding temperature and better efficiency. It has been observed that increasing in PF (0.25-1) factor increases the PV generation due to increase in area of PV modules and seen for the months of February to September.

CONCLUSIONS

This research study focuses on studying the effects of the length and orientation of PV overhangs as shading devices on an ECBC compliant generic office building in warm and humid climatic zone of Chennai (India) to understand the variation of each of the building load (HVAC and Lighting), PV yield with the change in parameters like the tilt of the shading, its length, fenestration properties and climate on an annual basis.

A general trend is noticed that the lighting energy for tilted orientation is more than the one at 90° tilt implying that daylight integration is negatively affected by a tilt in the shading. It is also noticed that the lighting requirement decreases as the projection factor increases. The cooling energy consumption decreased with increase in PF up to an optimum limit after which it started increasing with increase in overhang length due to change in fenestration properties. The tilted overhang with PF 0.25 has the lowest cooling load and the difference between maximum and minimum cooling load is very high. Tilted overhangs, in general, have a lower cooling energy requirement as compared to the 90° tilt overhangs. Heating is a small part of building load as compared to the cooling load. Thus despite a negative effect on heating load, mounting of overhang is recommended.

Increasing in PF (0.25-1) factor increases the PV generation and in the months of February to September good power generation has been found as compared to remaining months

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