COMPARISON OF DIFFERENT TYPE OF CONFIGURATIONS FOR PHOTOVOLTAIC FAÇADE IN COMPOSITE CLIMATIC ZONE OF INDIA (NEW DELHI)

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ABSTRACT:
The paper presents the simulation based analysis of the Building Integrated Photovoltaic (BIPV) system for a modeled test chamber located in a composite climatic zone (New Delhi) and compliant to Energy Conservation Building Code (ECBC) of India. The model is simulated using EnergyPlus software for BIPV energy generation and cooling/heating consumption .The analysis has been carried out by considering typical perimeter-core zoning pattern. PV system installation has been considered only on the south wall of 30 m^2 area. The following configurations (cases) have been analyzed in the study;

- ECBC compliant test chamber without PV on wall.
- PV attached on ECBC compliant model.
- PV attached on wall after removing insulation layer from exterior wall.
- PV on wall without insulation and with non-ventilated air gap.
- PV on wall without insulation having ventilated air gap.

The energy yield from BIPV and consumption for cooling and electricity generation has been compared for the above cases.

KEYWORDS: BIPV Performance, ECBC, EnergyPlus, PV simulation, PV on wall, Composite climate.

01. INTRODUCTION

Demand of energy in the building sector is increasing at a fast pace and currently the residential and commercial building sectors account for about 33% of the total electricity consumption in India with an average growth rate of 12-14% per year. Beside this, 66% of the building stock that would be required by 2030 is yet to be constructed with incremental addition of 1.3 billion Sq.mtr. every year [1]. The use of RE (Renewable Energy) applications in buildings is thus of importance at this stage to reduce dependence on commercial energy sources and enhance energy performance.

Among renewable energy sources the photovoltaic is a proven option for use in building sector as it offers a dual advantage of replacing construction material component and also has capability of electricity generation. The photovoltaic construction elements integrate in buildings and other architectural structures are termed as building-integrated photovoltaic's (BIPV) and building integrated photovoltaic thermal (BIPVT) system is another variant with promising applications. BIPV are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades [2]. Thus, BIPV is more than just mounting solar panels on a roof as it constitutes integration of solar electricity into the design of a building or structure so that the solar components also serve as structural or design elements.

The advantage of integrated photovoltaic over more common non-integrated systems is that the initial cost can be offset by reducing the amount spent on building materials and labor that would normally be used to construct the part of the building that the

The depth of perimeter zones is 3.6m. All the five zones are considered to be conditioned office areas.

2.4 Building Construction

2.4.1 Wall and Roof construction

The construction of the building is according to the ECBC standards [7]. The wall and roof construction is layer-by-layer construction. External Wall is made of double brick of total thickness 220mm. The wall has cement plaster of 6.4mm thickness on both sides. The inner side of wall is insulated and thickness is 64mm. The equivalent exterior wall has thickness 0.2938m and U-value 0.440 W/m^2-K. Internal partition walls are made of single brick construction of thickness 110mm. The internal partition wall has cement plaster of 6.4mm thickness on both sides. No insulation has been used in the construction of internal partition walls. These walls have no sun and wind exposure. The detail of each construction element is given below table 01;

Table 01 Building construction details

S.No.	Surface	Layers	Dimensions	Thickness	Thermal Conductivity (W/m^2-K)	Thermal Resistivity (m^2-K/W)
1	**Wall**	01.Cement 02.Double Brick 03.Cement 04.Insulation	15m×3.5m	0.2938m	0.440	2.27
2	**Roof**	01.Cast concrete 02.Cement 03.Insulation	15m×15m	0.3717m	0.409	2.44
3	**Door**	Plywood	1.5m×2.5m	0.0508m	2.953	0.233

The roof is made of 0.3m concrete block from outside having the total area of 225m^2. After that it has 6.4mm cement plaster. The batt Insulation material of 65.3mm is placed on the inside surface of whole roof. The equivalent exterior roof has thickness 0.3717m and U-value 0.409 W/m^2-K.

2.4.2 Window and Door construction

Windows on all four sides together constitute a WWR of 27%. Single glass has been used for window construction. U-value and SHGC of glass for composite climatic zone are 3.30 W/m^2-K and 0.25 respectively according to ECBC guidelines.
Exterior door on the north wall has been made of plywood and thickness is 0.0508m. After simulation the U-value of the door is 2.953W/m^2-K.

2.4.3 Occupancy, Equipment and Lighting

The number of occupants has been taken for the building is 6 for four zones; North, East, South and West. In Core the number of occupants is 8. Thus, 7m^2 area is allotted to each person. In order to simulate the heat gain from the people, the activity level of the occupants has to be set for each of the zone as "Seated, Reading", the associated heat gains is 100W each sensible and latent according to ASHRAE Fundamentals (2005). These values are taken from the table available in EP software.
The EnergyPlus software requires the radiant and convective portion of heat load from the electric components. Including all lighting system components (lamps, ballasts, task fixtures and furniture-mounted fixtures) an LPD value of 10.8 W/m^2 has been taken for energy calculation. The heat gain from the lights is assumed to be 40% by radiation. 100% lights are available from 9 a.m. to 6 p.m. in weekday but to

maintain an LPD level up to 10.8W/m^2 daylight sensors are used for controlling. In weekend and holydays all lights are off. For cooling, a packaged terminal air conditioner (PTAC) system is used for each zones of the building.
The working hours in the building is 9 a.m. to 6 p.m. for weekdays and for weekend and holydays it's closed.

2.4.4 Composite climate

A climate zone that does not have any season for more than six months is classified as composite zone. The composite zone covers the central part of India. Some cities that experience this type of climate are New Delhi, Kanpur and Allahabad. A variable landscape and seasonal vegetation characterize this zone. The intensity of solar radiation is very high in summer with diffuse radiation amounting to a small fraction of the total. In monsoons, the intensity is low with predominantly diffuse radiation. The maximum daytime temperature in summers is in the range of 32 – 43 ºC, and night time values are from 27 to 32 ºC. In winter, the values are 10 to 25 ºC during the day and 4 to 10 ºC at night.

03. METHODOLOGY

For achieving the objective, study is divided into following three stages.

1. Building Modeling
2. PV Integration and Simulation
3. Simulation Result Analysis

All these stages are followed one by one. The details of each step are given below.

3.1 Building Modeling

3.1.1 Building envelope Design and building load

Designing of building envelope is started from the modeling of 3D geometry of the building with the help of the GoogleSketchUp8 modeling software. After designing 3D geometry of the building the idf file is generated with the help of Legacy OpenStudioSketchUp Plug-in. then, this idf file is imported in EnergyPlusV-8-1-0 which is an energy simulation engine.
In EnergyPlus simulation software material for building elements like wall, roof, window etc. is chosen which is followed by the construction of all building elements using different types of materials. The details of each construction are given in the chapter test chamber description. After completing the design of the building envelope the load is defined for the building. As the building is considered an office building following loads are taken into account;

1. Lightening load
2. Equipment load
3. HVAC load

3.1.2 PV Integration

After the building modeling according to ECBC, now PV modules are attached to the exterior wall of the south zone with different configuration. The available South wall area is 30 m^2 for PV integration. In this study Crystalline- Si cell module of 80W_p was used. In this module 36 cells are connected in series. The active area of the module is 0.63 m^2. Thus, 46 models have been integrated on the south wall of the building. The total capacity of the install PV system on building façade is 3680W_p. This PV system is connected to grid.

3.1.3 PV configuration for building façade

The study has been done of five configurations for composite climatic zone in India which are as follows;

1. Building according to ECBC guidelines without PV modules
2. Building according to ECBC guidelines with PV modules
3. Building with PV module without insulation
4. Building with PV module without insulation and an air cavity between the PV module and wall
5. Building with PV module without insulation and a naturally ventilated air gap between the PV module and wall

04. RESULTS AND DISCUSSION

4.1 Simulation Variables

Simulation results have been analyzed in Microsoft Excel by making comparison graphs. Some output variables which have been analyzed are as follows;

01. Zone Electric Equipment Electric Energy.
02. Zone Lights Electric Energy.
03. Heating Coil Electric Energy.
04. Cooling Coil Electric Energy.
05. Zone Air Temperature.
06. Zone Packaged Terminal Air Conditioner Electric Energy.
07. Site Outdoor Air Dry bulb Temperature.
08. Surface Inside Face Conduction Heat Transfer Rate.
09. Surface Inside Face Temperature.
10. Surface Outside Face Temperature.
11. Inverter AC Output Electric Energy.
12. Transformer Output Electric Energy.

All these variables are collected for all configurations as well as for composite climate zone of India (New Delhi).

4.2 Results Analysis for Composite Climatic Zone (Annually and Monthly)

The composite zone covers the central part of India. Some cities that experience this type of climate are New Delhi, Kanpur and Allahabad. New Delhi has been selected for this study. ECBC base (case 1) and all its variations have been simulated in the composite weather condition of New Delhi (India). The simulation results have been analyzed on annual as well as monthly basis which are as following;

4.2.1 Annual Results and its Analysis

The annual electricity consumption of south zone of the building is 430.95 kWh in lighting, 1123.20 kWh in equipment, 1911.58 kWh in cooling, and 153.19 kWh in heating. This shows that most of the electrical energy is consumed by HVAC system (especially in cooling) within the south zone of the building (shown in figure 3).

Now photovoltaic is attached to the south exterior wall of the ECBC building (case 2) and simulated. The simulation results shows that the electrical energy consumption is remain same for equipment and lighting. The electrical energy consumption in cooling is increased to 1929.83 kWh and in heating is decreased to 146.59 kWh. The variation in cooling/heating is due the fact that the heat gain into the inner environment of the south zone of the building is more from the PV wall as compared to normal wall. Thus, the total electrical energy consumed by south zone is 3630.58 kWh and generated by photovoltaic is 2958.22 kWh (shown in figure 3).

The insulation of the photovoltaic wall of the south zone is removed (case 3) and simulated. The simulation results shows that the electrical energy consumption remain same for equipment and lighting. The electrical energy consumed in cooling is increased to 2163.37 kWh and in heating it is decreased to 144.08 kWh. The electrical energy generated by photovoltaic is increased to 2985.57 kWh (shown in figure 5.1) because most of the heat is transferred to the inner surface of the wall through conduction. As there is no insulation the inner environment of the south zone gains more heat from that wall through convection.

In the fourth case an air gap is provided between the photovoltaic layer and the south zone wall and simulated. The width of cavity is 0.5m. There is no any air movement between the exterior environment and cavity air. The simulation results shows that the electrical energy consumption remain same for equipment's and lighting. The electrical energy consumed in cooling is decreased to 1873.57 kWh and in heating is increased to 178.28 kWh. The electrical energy generated by photovoltaic is decreased to 2715.87 kWh.

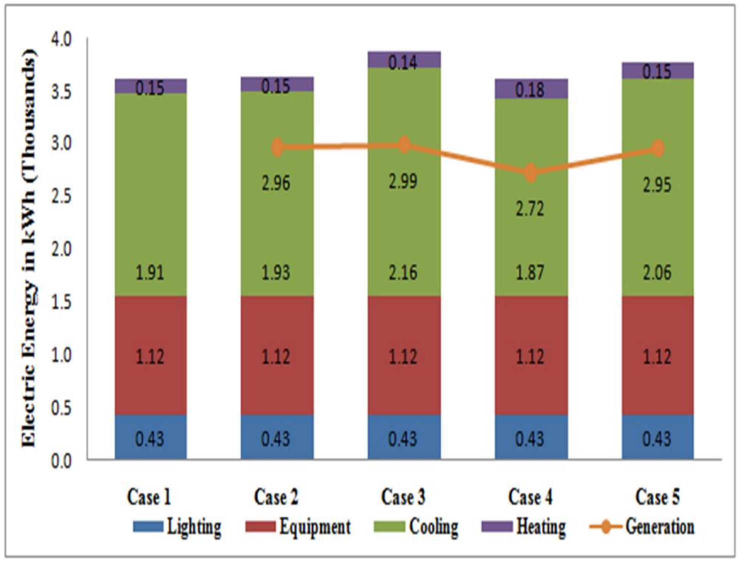

Figure03. Annual electricity consumption and PV generation at New Delhi

In the fifth case, air movement between the exterior environment and cavity air is provided through 5% openings and simulated. The width of cavity is 0.5m. The simulation results shows that the electrical energy consumption remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is increased to 2064.69 kWh and in heating is decreased to 154.20 kWh. The electrical energy generated by photovoltaic is increased to 2946.83 kWh.

4.2.2 Monthly Results and its Analysis

It was found that there is variation in the consumption of electricity for lightening and equipment's. The variation in equipment electricity consumption is due to the variation in the number of working days in each month and for lightening due to the variation in indoor light for different months.

In the month of January and December heating is required.

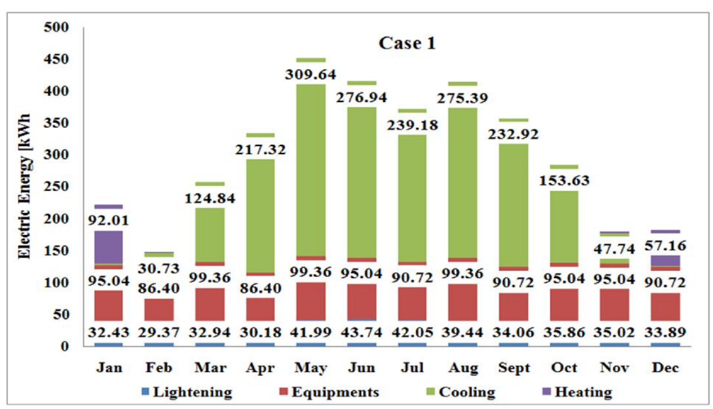

Figure04. Monthly electricity consumption of case 1 at New Delhi

In the month of May highest cooling consumption (309 kWh) is there in case 01 as shown in figure 04.

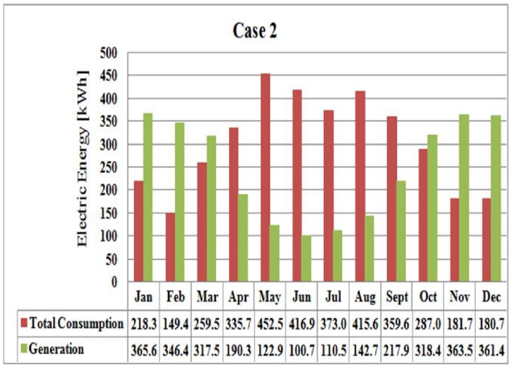

Figure05.Monthly electricity consumption of case 2 at New Delhi

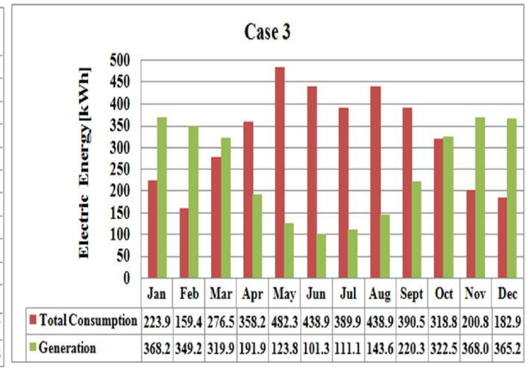

Figure06.Monthly electricity consumption of case 3 at New Delhi

Similar pattern of variation in lightening and equipment consumption is followed in all cases. But in case 3 the electricity consumption in cooling is slightly increased in all months as heat is transferred to the inner surface of the wall through conduction. In the month of January, February, March, October, November and December the electricity generation is more than the electricity consumption compared to the remaining month's generation (shown in figure 05 to figure 08). The attributed reason is due to the incident solar radiation which is more on vertical wall in winters compared to summer months.

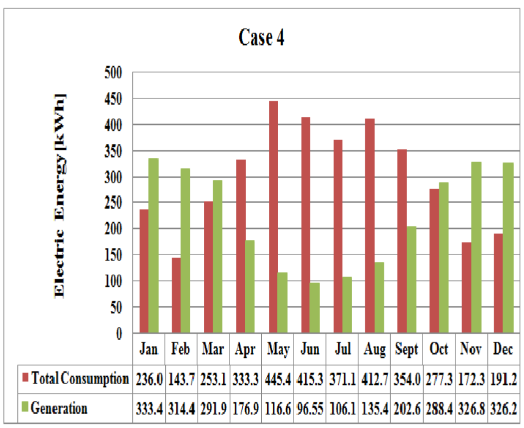

Figure07.Monthly electricity consumption of case 4 at New Delhi

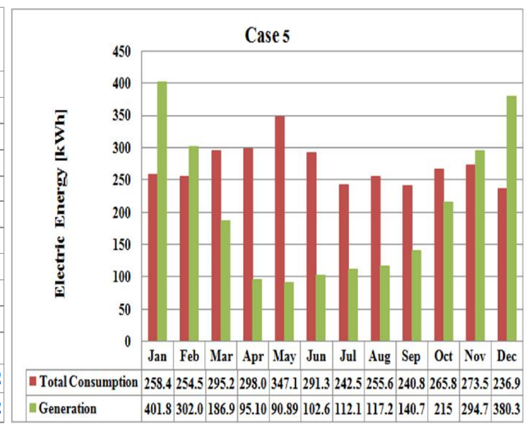

Figure08. Monthly electricity consumption of case 5 at New Delhi

In case 5 (PV on wall with ventilated air gap) there is maximum electricity generation from November to February because of good incidence of solar radiation on the PV wall and proper heat dissipation by air which is effective in maintaining the module temperature and improve module efficiency. From April to August generation is less as the maximum solar radiation (greater than 1000W/m^2) is on PV wall which increase module temperature and lowers its efficiency.

CONCLUSIONS

The building model and its various configurations of PV integration on façade have been simulated in the EnergyPlus for composite climate of India (New Delhi). The results for annual and monthly energy consumption for cooling and PV electric generation have been obtained and analyzed. The conclusion from this analysis can be summarized as following;

a) PV on wall without insulation and with non-ventilated air gap configuration has the lowest cooling consumption which is also lower than the ECBC compliant building without PV on wall configuration. Thus it can be a promising option for avoiding use of insulation on the wall while still remaining ECBC compliant.

b) Electricity generation from PV integrated wall of building for the above mentioned configurations have been compared. It has been found out in all the analyzed configurations, PV attached on wall after removing insulation layer from exterior wall configuration has highest amount of electricity generation on annual basis.

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