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EVALUATION & ANALYSIS OF DIFFERENT TYPES OF CONFIGURATIONS FOR PHOTOVOLTAIC PANELS IN THREE VARIOUS INDIAN REGIONS

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ABSTRACT
Though buildings and constructional development provides numerous benefits to society and people, they also have significant environmental and health impacts. Further Building also have a significant impact on usage of energy and the environment. The energy presently used by the building sectors continues to increase, primarily because new buildings are being constructed and energized at a rapid rate than the older ones as they retire. Nowadays Green buildings are a very prominent and promising option which provides a holistic way to reduce overall impact on environment and human health by Reducing trash, pollution and degradation of environment and also efficiently using energy, water and other resources.

Now for achieving the mentioned objective our study is divided into three stages 1)Building Modelling 2)PV Integration and Simulation 3)Simulation Result Analysis. The study is started with the designing of the building and deciding its components and loads. Designing of building envelope is started from the modelling of 3D geometry of the building. It has been done with the help of the GoogleSketchUp8 modelling software. After designing 3D geometry of the building the idf file is generated with the help of Legacy Open Studio Sketch Up Plug-in. then, this idf file is imported in EnergyPlusV-8-1-0 which is an energy simulation engine[4]. Different schedules are made for different components of the building. Some component schedules are :HVAC Schedule, Cooling Coil Schedule, Heating Coil Schedule, Lightening Schedule, Equipment Schedule, Occupancy Schedule and Activity Schedule. Energy calculation for the building has been done in three different climatic zones of India viz; Hot and Dry, Warm and Humid, Composite and Cold and Cloudy. Up to this stage the ECBC base is ready for simulation. Then PV modules are attached to the exterior wall of the south zone. Energy used for construction and operating the building should be minimized[1-2-3]. Thus, taking into account above mentioned factors buildings should always be designed and built in an energy efficient ways.

Finally, the results of the analysis and simulation introduces not only an environmentally compatible but also a more efficient BIPV system. Further, the proposed evaluation and analysis will definitely be useful in future prospects for all BIPV enthusiasts.

KEYWORDS: Building Envelope, Component Schedules, Energy Plus, PV Modules.

1. INTRODUCTION

Energy utilisation and its techniques are one of the major considerations of the present 21 st century due to the shortage of conventional non-renewable sources of energy such as coal and petroleum and their limited reserves. Increased environmental pollution, increased gap between energy supply and demands, and non-uniform distribution of renewable energy sources like solar energy, wind energy, geothermal energy and energy from ocean currents intensifies the energy problems further. Energy recovery systems and techniques have also been encountered with the problems of utilization and availability of energy at different time intervals and hence requires systematic and diversified energy storage systems and techniques for uninterrupted power supply requirements. In this context The 19th century was the age of coal, 20th century was that of fossil fuels mainly coal and petroleum while the 21st century in that we are living in, is surely the age of solar energy. The reason for encouraging the use of solar energy is due to number of facts, firstly fossil fuel reserve is reducing day by day due to their rapid and repetitive use and secondly the emissions of CO2 from the combustion of the fossil

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fuels are the main reason for various climatic change. Hence, the use and application of renewable energy and most imperatively the energy from the sun which is available in abundance and is absolutely free is focused upon to reduce CO2 emissions. Solar energy should also be the main factor of consideration for architects, engineers, regulatory authorities and clients when creating the buildings and constructional environment. In this context Buildings should always be designed and built in an energy efficient way. Energy used for construction and various operations by the occupants of the building should be drastically minimized. In the case of new construction this could be achieved through appropriate and specific orientations, subsequent use of passive solar energy and selection of appropriate relative solar energy materials. Appropriate materials also means here that they are produced and extracted by very minimal use of energy as far as possible. In buildings energy consumption can be reduced significantly by insulating the building shell, use of windows with better U-values for thermal performance, exchange of heating systems etc. The remaining energy demand should be covered by active systems that use energy from a renewable source.

Depending on their level of integration and on the functionalities they can perform, they are classified into;

1) BAPV

It refers to concepts where the photovoltaic systems are mounted on the building existing structure and therefore do not add any additional value beside thus of producing electricity. As shown in the figure PV modules are installed on the top of the existing roof of the building. BAPV is normally added to the building after the process of construction is finished.

2) BIPV

On the other hand photovoltaic elements have been present in the project from the very beginning. It is a part of a holistic design. Thus, for the BIPV, solar modules have the role of a building element in addition to the function of producing electricity. BIPV on Panels has several advantages. It not only generates electricity but also helpful for reducing cooling/heating load of the building. In BIPV, the installation of PV should be properly designed. Otherwise, we can get less benefit. Thus, it is necessary to study the effect of photovoltaic integration on building Panels and know which design of photovoltaic integration is beneficial to us.

2. LITERATURE BASED ON EFFECT OF WEATHER ON VARIOUS SOLAR FACADES

This chapter introduces the study of various researchers at different location in the field of Energy simulation. In this chapter we also discuss the results & conclusion of their studies.

2.1 Literature on BIPV and its Technologies

Peng et al[5] have made a model of multi-layer normal Panels and PV wall mounted on a multi-layer Panels and found that The heat gains through the both types of walls were positive in almost all of the year, and were negative only during certain time in winter. The annual reduction ratios of heat gain and heat loss through the south-facing PV wall were about 56.2% and 32%, respectively.

Han and **Lu[6]** have set up a model in hot weather conditions in Hong Cong of naturally ventilated semi-transparent PV Panels and conventional clear glass Panels and found that the PV Panels system could not generate electricity but also achieve potential energy savings by reducing the air conditioning cooling load and simultaneously provide visual comfort in the indoor environment.

Gaillard et al[7] have presented the first experimental observations of an innovative double-skin PV facade, with natural convection corresponding to a summer operational mode. They found that the kinematic behavior of the cavity is strongly influenced by the wind means the wind significantly cooled PV surfaces through external transfer, but other temperatures were not strongly affected.

Kanchan et al[8] have calculated the electrical and thermal energy analysis for six types of PV modules(m-Si, p-Si, amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and a hetero junction comprised of a thin a-Si PV cell on top of a c-Si cell (HIT)) for the Srinagar, India.

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Zhongzhu Qiu et al[9] established that outward ventilated double PV Panels is the most energy efficient as compared with conventional absorptive single Panels, un-ventilated double PV Panels. The annual electricity generation by the semi-transparent solar cell is about 7% of the total electricity consumption to meet cooling and heating demand of the building occupancy.

Gayathri et al[10] have installed PV modules are installed as roof of an experimental laboratory at Indian Institute of Science, Bangalore. They observed that significant deviation in individual panel efficiency and array efficiency, System efficiency and output depend on the interplay between various parameters such as solar insolation, cell and ambient temperatures, the average efficiency of the entire system is ~6% over the year with a performance ratio ~0.5, the average inverter efficiency was found to be 91%.

Plotnikov et al[11] simulated using PV watts for different transparent Thin Film modules for New York city, the results shows that PV as window gives more energy yield as compared to PV as fixed rooftop option. They have also demonstrated that the addition of selected light absorbing and/or reflecting elements can adjust the spectrum of light transmitted through and reflected from a completed module.

Menezo et al[12] carried out an experimental study to investigate the effect of the geometrical configuration on the thermal performance of a series of vertical heaters cooled by natural convection of air. The aim of the work was to investigate the physical mechanisms which influence the thermal behavior of a PV Panels.

Atmaja[13] has investigated the effect of Panels azimuth, Inclination angle and Pitch between the PV modules on the Panels on PV penetration level due to change in insolation level on the building envelope. They calculated an optimum angle in horizontal and vertical inclination.The calculation also uses installation distance to module length ratio to achieve a greater solar insulation on the PV modules.

Penga et al[14] have highlighted the issues related to BIPV architecture design, support systems, horizontal and vertical support beams for module mounting. To resolve problems associated with the existing photovoltaic structures in China, the author describes a building photovoltaic construction that allows convenient maintenance and replacement of photovoltaic components.

Stamenic et al[15] have estimated the irradiance effect on BIPV, generally the BIPV systems are under shadowing conditions, developed an algorithm for calculating power output of the photovoltaic array derived from the ideal diode equation using the single diode model of a photovoltaic cell.
Oliver M et al[16] developed the performance model from analysis of the open circuit voltage, maximum power point voltage and maximum power point current of the individual modules comprising the BIPV array and evaluated the same from economic view point.

2.2 Literature for EP Software Validation

Griffith et al[17] validate the Energy Plus implementation of the flat-plate solar collector, results were compared to the TRNSYS Type 1 flat-plate solar collector, which is also based on the same model equations from ASHRAE and Duffie and Beckman. The Energy Plus model and Type 1 model were compared side-by-side by extracting and wrapping both FORTRAN subroutines with a thin layer of control code to exercise the models. Although the two models require different input variables and units, the control code made all necessary conversions. The results agreed exactly for most conditions, with the exception of very low incident angles where there were only very minor differences.

2.3 Literature on PV Module Conductivity

Lee et al[18] measured the thermal conductivity of each layer in encapsulated Si solar cells. Following table shows the thermal conductivity of each layer

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Table 2.1 Thermal conductivity of each layer in encapsulated Si solar cells

S No.	Layer	Thickness [mm]	Thermal conductivity [$W*m^{-1}K^{-1}$]
1	Glass	3.0	0.98
2	EVA	0.5	0.23
3	ARC	$(0.06\text{-}0.1)*10^{-3}$	1.38
4	Si	0.25-0.4	148
5	EVA	0.5	0.23
6	Tedlar	0.1	0.36

The above measured values of the PV module are used in the energy calculation of building. After doing this survey we can conclude that the lots of research have been done on PV as an element of building Panels. But no one compare the PV installation methods on the building Panels. Thus, in our study we have compared the different type of PV installation configuration on building Panels. In this work a new way of improving the heat dissipating ability and PV efficiency of the solar cells by enhancing the thermal conductivity of the rear EVA layer was reported. The thermal conductivity, electrical resistivity, degree of curing of the EVA encapsulating composites and the PV efficiency of the solar cells were investigated. Filling with the thermal conductive fillers enhanced the thermal conductivity of the composites effectively.

3. RESEARCH METHODOLOGY

In our study we have compared the different type of PV installation configuration on building Panels. This chapter introduces the steps involved in the study. For achieving the objective study is divided into three stages:

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

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

3.1 Building Modelling

The study is started with the designing of the building and deciding its components and loads. Building modelling is completed after the completion of four parts;

3.1.1 Design Building Envelope

Designing of building envelope is started from the modelling of 3D geometry of the building. It has been done with the help of the GoogleSketchUp8 modelling software. After designing 3D geometry of the building the idf file is generated with the help of Legacy Open Studio Sketch Up Plug-in. then, this idf file is imported in EnergyPlusV-8-1-0 which is an energy simulation engine.

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In Energy Plus 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.

3.1.2 Define Building Load

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

Each type of load is defined in the energy simulation software one by one. The details of each load and its component are provided in the chapter test chamber description.

3.1.3 Scheduling

Different schedules are made for different components of the building. Some component schedules are;

1. HVAC Schedule
2. Cooling Coil Schedule
3. Heating Coil Schedule
4. Lightening Schedule
5. Equipment Schedule
6. Occupancy Schedule
7. Activity Schedule

Each schedule is made after taken care of office timings and vacations.

4. WEATHER DATA

Energy calculation for the building has been done in three climatic zones of India;

- Warm and Humid (Mumbai)
- Hot and Dry (Vadodra)
- Cold and Cloudy (Guwahati)

Form each climatic zones of India a city is chosen and the weather file of that city which provided by ISHRAE is uploaded in the simulation software.

4.1 PV Integration and Simulation

Up to this stage the ECBC base is ready for simulation. Now PV modules are attached to the exterior wall of the south zone. This is the south facing wall of the building.

4.1.1 Selection of PV Module

The available South wall area is 30 m^2 for PV integration. We have used Crystalline-Si cell module of 80 Wp. 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 Panels is 3680 Wp. This PV system is connected to grid.

4.1.2 PV Layer Construction

For involving PV modules in energy calculation of building an extra layer is added to the south wall. Figure 4.2 shows the layers in construction of PV module.

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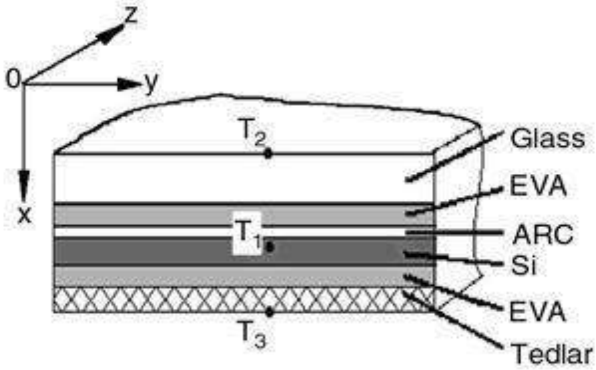

Figure 4.1 Construction of PV modules [14]

Thermal properties of each material and its thickness are specified in the EP software for the construction of PV module.

4.1.3 PV Configuration for Building Panels

The study has been done on five type configurations which are as follows;
Case 1: It is the first configuration which has been considered. In this configuration the building is designed according to ECBC guidelines. The PV modules are not installed in this configuration.

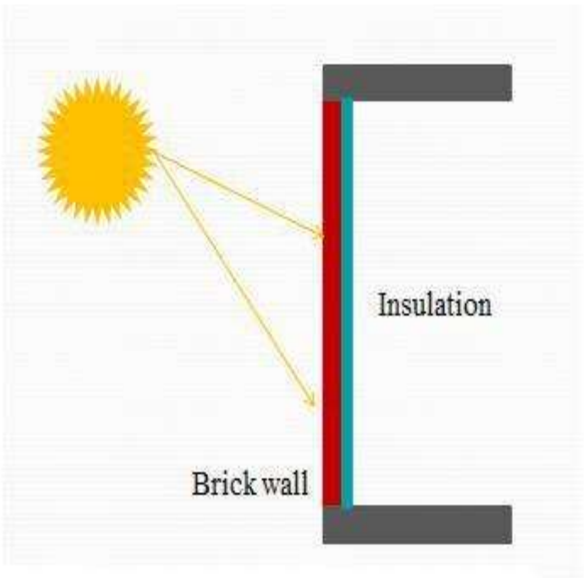

Figure 4.2 ECBC south wall

Case 2: In second configuration the building is designed according to ECBC guidelines and PV modules are installed on the south wall of the building. In this configuration no gap is provided between the PV modules and south wall.

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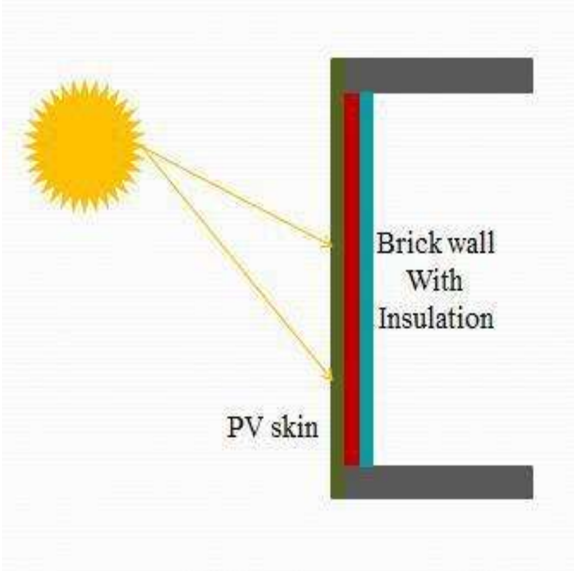

Figure 4.3 ECBC south wall with PV

Case 3: In third configuration the insulation from south wall has been removed. Then, PV modules have been installed on the south wall of the building.

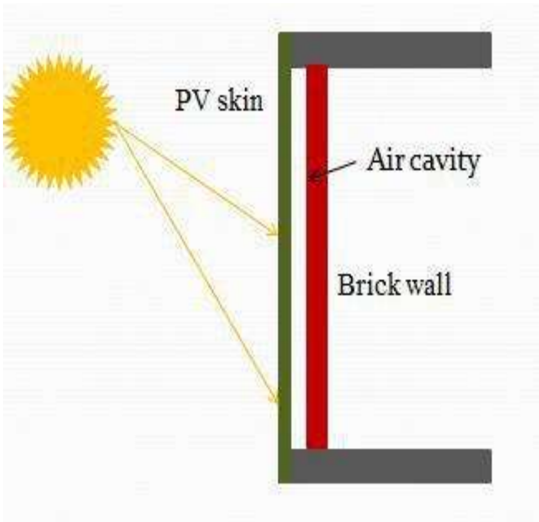

Figure 4.4 South wall with PV without insulation

Case 4: In fourth configuration PV modules have been installed on south wall of the building with an air cavity between the PV modules and wall. But no insulation has been provided to the south wall and also no ventilation has been given.

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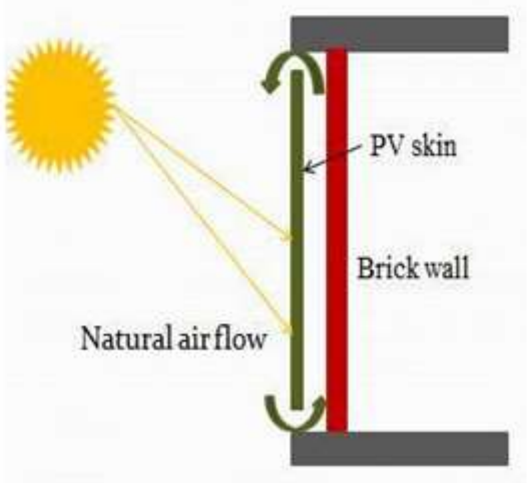

Figure 4.5 South wall with PV and air cavity

Case 5: In the last configuration PV modules have been installed on the south wall of the building with an air gap between PV modules and wall. A natural air flow has been allowed between them by providing sufficient opening on upper side and lower side of the wall.

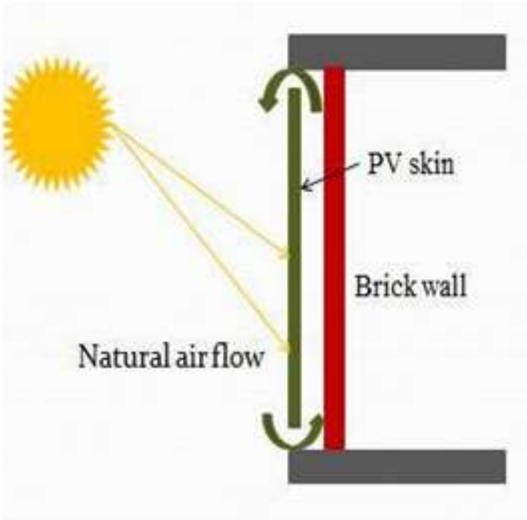

Figure 4.6 South wall with PV and Ventilation

4.1.4 Simulation

Now the ECBC base case and its configurations are simulated with the help of EP software. Then the simulation results are collected together and analyzed for different location of India.

4.1.5 Simulation Result Analysis

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

- Zone Electric Equipment Electric Energy
- Zone Lights Electric Energy
- Heating Coil Electric Energy
- Cooling Coil Electric Energy
- Zone Air Temperature
- Zone Packaged Terminal Air Conditioner Electric Energy

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- Site Outdoor Air Dry bulb Temperature
- Surface Inside Face Conduction Heat Transfer Rate
- Surface Inside Face Temperature
- Surface Outside Face Temperature
- Inverter AC Output Electric Energy
- Transformer Output Electric Energy

All these variables are collected for all configurations as well as for all locations.

5. RESULTS & ANALYSIS

5.1 Warm and Humid

The ECBC Base (Case 1) and all its combinations are simulated in the warm and humid weather condition of Mumbai. Now the analysis of simulation results on monthly basis as well as annual basis are as follows;

5.1.1 Annual Results and its Analysis

The annual electrical energy consumption in south zone of the test chamber is 460 kWh in lightening, 1123 kWh in equipment, 2656 kWh in cooling, and no heating required. This shows that most of the electrical energy is consumed by HVAC system (in cooling) within the south zone of the building.

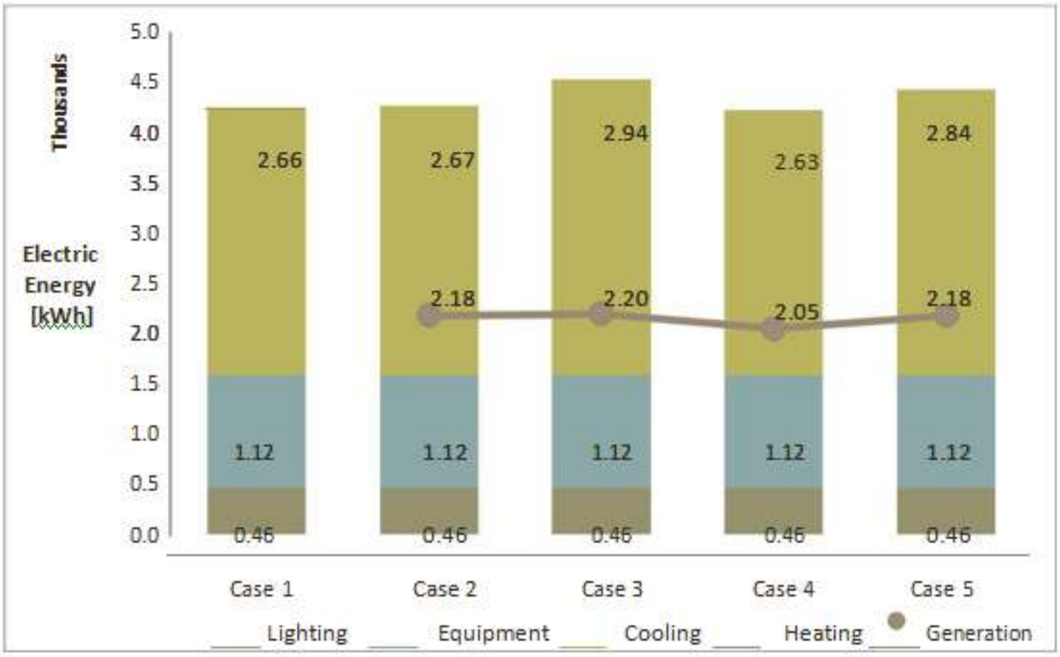

Figure 5.1 Figure Annual electricity consumption and PV generation at Mumbai

Now photovoltaic is attached to the south exterior wall of the building and simulated. The simulation results shows that the electrical energy consumption is remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is increased to 2675 kWh. Thus, the total electrical energy consumed by south zone is 4258 kWh and generated by photovoltaic is 2177 kWh. The insulation of the photovoltaic wall of the south zone is removed and simulated. The simulation results shows that the electrical energy consumption remain same for equipment and interior lighting. The electrical energy consumed in cooling is increased to 2938 kWh. The electrical energy generated by photovoltaic is increased to 2195 kWh.

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 not any air movement between the exterior environment and cavity air.

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The simulation results shows that the electrical energy consumption remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is decreased to 2635 kWh. The electrical energy generated by photovoltaic is decreased to 2047 kWh.

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 approx 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 2839 kWh. The electrical energy generated by photovoltaic is increased to 2178 kWh.

5.2 Hot and Dry

After doing the changes according to ECBC standards all five cases are simulated for the hot and dry weather condition of Vadodra. The simulation results are discussed into two parts; Annual basis and monthly basis which are as follows;

5.2.1 Annual Results and its Analysis

After simulating the Base case the annual electrical energy consumption in south zone of the building is 411 kWh in lighting, 1123 kWh in equipment, 2186 kWh in cooling and negligible in heating. This shows that most of the electrical energy is consumed by HVAC system (in cooling) within the south zone of the building.

Now photovoltaic is attached to the south exterior wall of the building and simulated. The simulation results shows that the electrical energy consumption is remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is increased to 2211 kWh. Thus, the total electrical energy consumed by south zone is 3745 kWh and generated by photovoltaic is 3017 kWh. The insulation of the photovoltaic wall of the south zone is removed and simulated. 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 2478 kWh. The electrical energy generated by photovoltaic is increased to 3045 kWh.

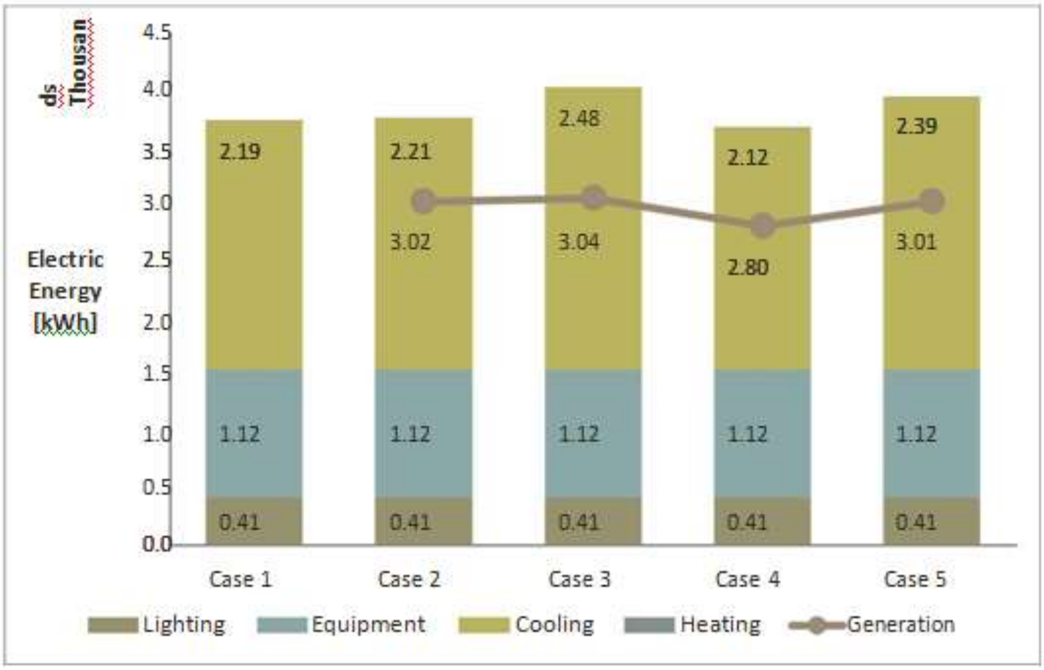

Figure 5.2 Annual electricity consumption and PV generation at Vadodra

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 approx 0.5m. There is not any air movement between the exterior environment air and air in the cavity. The simulation results shows that the electrical energy consumption remain same for interior

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equipment and interior lighting. The electrical energy consumed in cooling is decreased to 2124 kWh. The electrical energy generated by photovoltaic is decreased to 2799 kWh.

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 2393 kWh. The electrical energy generated by photovoltaic is increased to 3014.5 kWh.

5.3 Cold and Cloudy

After doing the changes according to ECBC standards all five cases are simulated for the cold and cloudy weather condition of Shillong. The simulation results are discussed into two parts; Annual basis and monthly basis which are as follows;

5.3.1 Annual Results and its Analysis

After simulating the Base case the annual electrical energy consumption in south zone of the test chamber is 540.85 kWh in lighting, 1123.20 kWh in equipment, 103.64 kWh in cooling, and 786.79 kWh in heating.

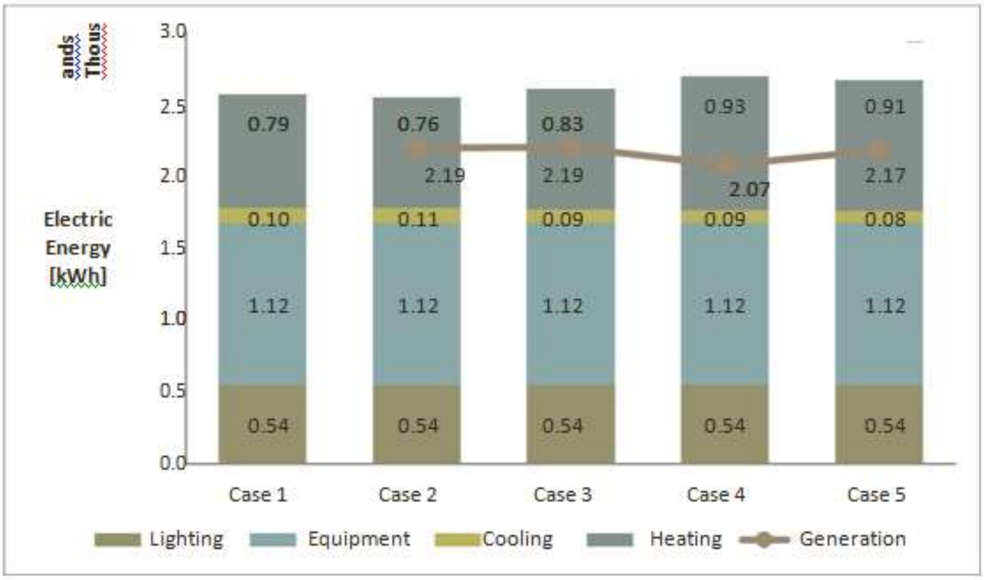

Figure 5.3 Annual electricity consumption and PV generation at Guwahati

Now photovoltaic is attached to the south exterior wall of the test chamber and simulated. The simulation results shows that the electrical energy consumption is remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is increased to 106.25 kWh and in heating is decreased to 763.11 kWh. Thus, the total electrical energy consumed by south zone is 2534.30 kWh and generated by photovoltaic is 2187.01 kWh.

The insulation of the photovoltaic wall of the south zone is removed and simulated. The simulation results shows that the electrical energy consumption remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is decreased to 94 kWh and in heating is increased to 833.29 kWh. The electrical energy generated by photovoltaic is decreased to 2191.10 kWh.

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 approx 0.5m. There is not any air movement between the exterior environment air and air in the cavity. The simulation results shows that the electrical energy consumption remain same for interior equipment and interior lighting. The electrical energy consumed in cooling is decreased to 86.96 kWh and in

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heating is increased to 929.03 kWh. The electrical energy generated by photovoltaic is decreased to 2066.52 kWh.

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 approx 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 decreased to 84 kWh and in heating is decreased to 906 kWh. The electrical energy generated by photovoltaic is increased to 2173 kWh.

6. CONCLUSION

To simulate the building, first a 3D model has been created in Google Sketch UP. After drawing the building model internal information of building has been added in the EP software and there after PV modules are integrated into building. The various configurations of PV integration on building Panels have been simulated in the EP and the results for annual and monthly energy consumption/ generation have been obtained. This opens up the possibility of comparing the various configurations and to figure out the potential of energy conservation without using insulation as well as highest possible generation from PV. The finding from this study can be summarized by dividing it into following parts;

6.1 Warm and Humid

The building model and its various configurations of PV integration on Panels have been simulated in the EP in warm and humid climate of Mumbai. The results for annual and monthly energy consumption/ generation have been obtained and analyzed. The conclusion from this analysis can be summarized as follows;

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) PV attached on wall after removing insulation layer from exterior wall configuration has highest amount of electricity generation.

6.2 Hot and Dry

The building model and its various configurations of PV integration on Panels have been simulated in the EP in hot and dry climate of Vadodra The results for annual and monthly energy consumption/ generation have been obtained and analyzed. The conclusion from this analysis can be summarized as follows;

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) PV attached on wall after removing insulation layer from exterior wall configuration has highest amount of electricity generation.

6.3 Cold and Cloudy

The building model and its various configurations of PV integration on Panels have been simulated in the EP in cold and cloudy climate of Guwahati. The results for annual and monthly energy consumption/ generation have been obtained and analyzed. The conclusion from this analysis can be summarized as follows;

a) PV on wall with insulation without air gap configuration has the lowest heating consumption. Thus no option for avoiding use of insulation on the wall has been found.
b) PV attached on wall with insulation layer without air gap configuration has highest amount of electricity generation.

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