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Comparative Study of Different Types of Configurations for

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Abstract—*Buildings have a significant impact on energy use and the environment. The energy used by the building sector continues to increase, primarily because new buildings are constructed faster than old ones are retired. Thus, Buildings should always be designed and built in an energy efficient way. Energy used for construction and operating the building should be minimized. For achieving the objective 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 OpenStudio SketchUp Plug-in. then, this idf file is imported in EnergyPlusV-8-1-0 which is an energy simulation engine. 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 all five climatic zones of India; Hot and Dry,Warm and Humid,Composite, Moderate/Temperate,Cold and Cloudy. Up to this stage the ECBC base is ready for simulation. Now PV modules are attached to the exterior wall of the south zone.*

Keywords:—*Building Envelope, Component Schedules, Energy Plus, PV Modules*

1. INTRODUCTION

The 19th century was the age of coal, 20th century was that of use of fossil oil while the 21st century in that we are, is 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 excessive use and secondly the emissions of CO_2 from the consumption of these fuels are the main cause of climate change. Hence, the use of renewable energy and most importantly the energy from the sun which is easily available and that free is encouraged to reduce CO2 emissions. Solar energy should be the main consideration for architects, engineers, regulatory authorities and clients when creating the built environment. In this context Buildings should always be designed and built in an energy efficient way. Energy used for construction and operating the building should be minimized. In the case of new construction this can be done through appropriate orientation, passive use of solar energy and selection of appropriate materials. Appropriate materials means they are produced or extracted by very little 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 DUST ON SOLAR COLLECTORS

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

Han and Lu 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. They also found decrement of 0.29% conversion efficiency in thin-film amorphous silicon solar cell technology with the temperature increment of 15.6°C [5].

Peng et al. 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. About 52.1 kW h of thermal energy could be saved yearly by replacing each square meter of south-facing normal wall with the PV wall, and accordingly 18.6 kW h of electric energy would be saved by the air conditioning system, which could be regarded as a 12.4% increase of the annual energy generation for PV system. The thickness of the air gap between the PV modules and multi-layer Panels had a significant influence on the thermal. The annual heat transfer through the PV wall decreased firstly with the increasing of the thickness and then increased after the air gap exceeding 0.06 m. performance of PV wall [6].

Gaillard et al. 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 [7].

Kanchan et al. 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 and found that HIT suitable for generating electrical power because it produces maximum annual electrical energy (810 kW h) and Si suitable for space heating applications because it produces maximum annual thermal energy (464 kW h) [8].

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. The outward ventilation, which represents chimney effect, of the ventilated photovoltaic double skin facade could cut down cooling load in summer, in contrast, increased the heating load in winter [9].

Gayathri et al. have installed PV modules are installed as roof of an experimental laboratory at Indian Institute of Science, Bangalore. Figure 2.4 shows the efficiency of the PV array and PV system. From that graph they observed;

1. Significant deviation in individual panel efficiency and array efficiency.
2. System efficiency and output depend on the interplay between various parameters such as solar insolation, cell and ambient temperatures.
3. The average efficiency of the entire system is ~6% over the year with a performance ratio ~0.5.
4. The average inverter efficiency was found to be 91% [10].

Plotnikov et al. 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. The authors also analyzed PV on windows for different orientation of the building and found that In comparison with a horizontally mounted rooftop array, vertical arrays in NYC, e.g., windows, still have excellent yearly production. For example, compared to the same array mounted horizontally on a rooftop, an unobstructed window array facing South will produce 75% as much, a window array facing East or West will produce 56% as much, and even a window array facing North will produce 24% as much as the same array on the rooftop. Clearly the energy payback time is much longer for the north-facing windows but if this is the architectural choice for aesthetic reasons. It is good to know that there is a significant energy payback. The light transmitted through a CdS/CdTe thin film structure is determined by the absorption spectrum of the materials. Since both semiconductors have stronger absorption in the blue spectral region, the natural color of the transmitted light appears bronze. In many applications this is undesirable. They have 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 [11].

Atmaja 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. BIPV is an emerging research topic to optimize building component replacement using certain types of PV module. The author conducted a strategic review on the optimum PV module installation to generate electricity from the building envelope. The Panelss and rooftops would be an object of building envelope to be deposited with a specific characteristic installation of PV module. Panels installation will be affected by the geographical position of the site, so a certain directions shall perform a higher electric energy production than the other directions. 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. Rooftop installation will consider the curved rooftop as a potential feeder either it was bonded or mounted. It is believed that overall performance of curved PV installation could outperform flat PV installation in certain time. Other calculation also performed to observe effective load carrying capacity (ELCC) against PV penetration level to perceive the optimum PV penetration level for high ELCC without resulting operational problems [12].

Menezo et al. 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 is to investigate the physical mechanisms which influence the thermal behavior of a PV Panels. Furthermore increasing the heat transfer rate from the PV surfaces increases the conversion efficiency of the PV modules since they operate better as the working temperature is lower. The test section consists in a double vertical wall, 2 m high, and each wall is constituted by 10 different heating modules 0.2 m high. The separating distance between the walls is varied from 0.03 to 0.16 m, and the convective heat flux at the wall ranges from 75 to 200 W/m2. In this study, the heated section is 1.6 m in height. Different heating configurations are analyzed, including the uniform heating mode and two different configurations of non-uniform, alternate heating. The experimental procedure allows the wall temperature and local heat transfer coefficient to be inferred and shows that the proper selection of the separating distance and heating mode can noticeably decrease the surface temperatures and hence enhance the conversion efficiency of PV modules [13].

Penga et al. have highlighted the issues related to BIPV architecture design, support systems, horizontal and vertical support beams for module mounting. Based on this background, this paper highlights some issues associated with the following: how to choose between BIPV and BAPV, whether it is necessary for photovoltaic components to last as long as buildings and how to design BIPV structures. 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 [14].

Stamenic et al. 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. The low irradiance efficiency of photovoltaic modules is important to the optimization of BIPV systems. When photovoltaic modules are integrated into a building, architectural design considerations compete with maximizing photovoltaic energy production. As a result, BIPV arrays are often not facing south and are frequently mounted vertically. Under these conditions, a greater portion of the total sunlight striking the array is diffuse or at high angles of incidence. In northern latitudes a significant amount of the total yearly energy is produced at low light levels. A grid-connected array of BIPV modules integrated into the BCIT Technology Centre building in Burnaby, B.C. was used for assessing the accuracy of an energy performance model developed for BIPV systems. The BIPV system uses AC modules and a computerized data acquisition system for monitoring the performance of modules and inverters. The performance model was developed from analysis of the open circuit voltage, maximum power point voltage and maximum power point current of the individual modules comprising the BIPV array [15][16].

2.3 Literature for EP Software Validation

Griffith et al. validate the EnergyPlus 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 EnergyPlus 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 [17].

2.3 Literature on PV Module Conductivity

Lee et al. measure the thermal conductivity of each layer in encapsulated Si solacells shown. Following table shows the thermal conductivity of each layer

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.

3. RESEARCH METHODOLOGY

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 OpenStudio SketchUp 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.

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.

Weather Data

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

1. Hot and Dry (Ahmedabad)
2. Warm and Humid (Chennai)
3. Composite (New Delhi)
4. Moderate/Temperate (Bengaluru)
5. Cold and Cloudy (Shillong)

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.

3.2 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.

3.2.1 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.

3.2.2 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.

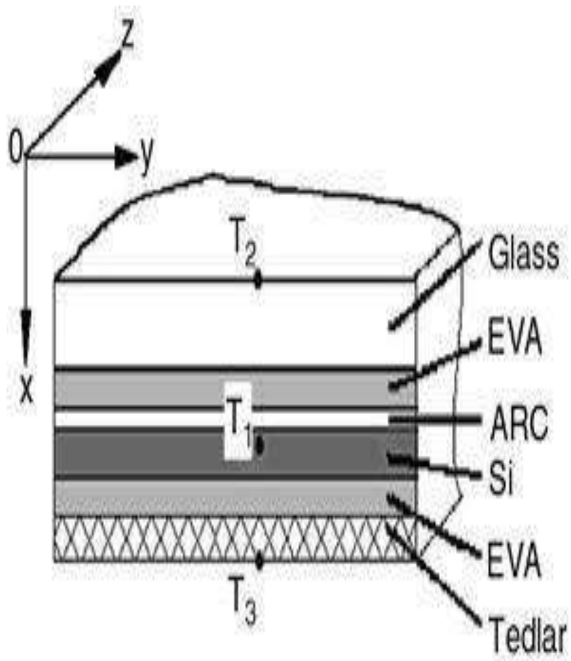

Figure 3.1 Construction of PV Modules [14]

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

3.2.3 PV Configuration for Building Panels

The study has been done on five type configurations which are as follows;

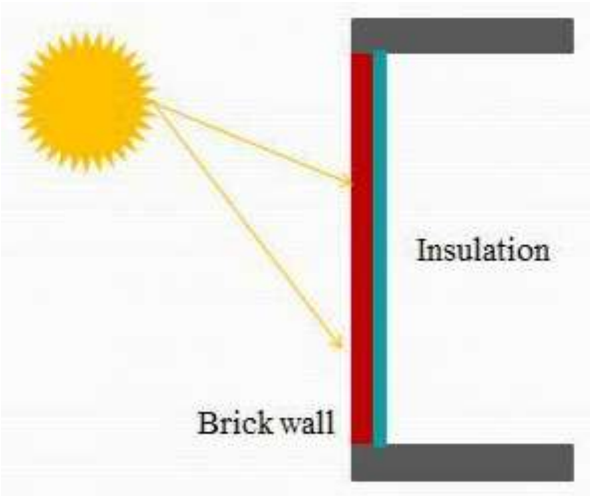

Figure 3.2: ECBC south wall

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.

***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.

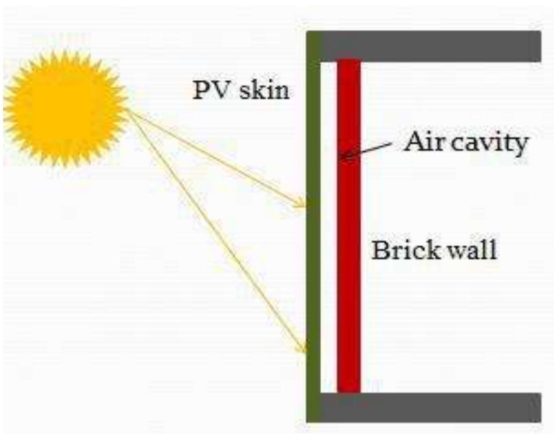

Figure 3.3 ECBC south wall with PV

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.

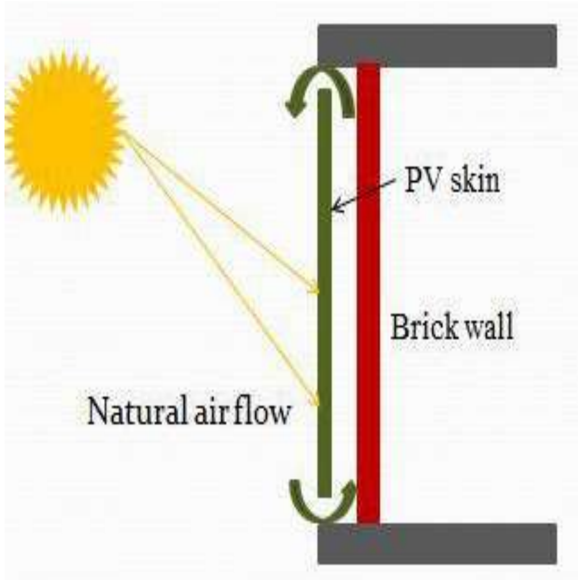

Figure 3.4 South wall with PV without insulation

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.

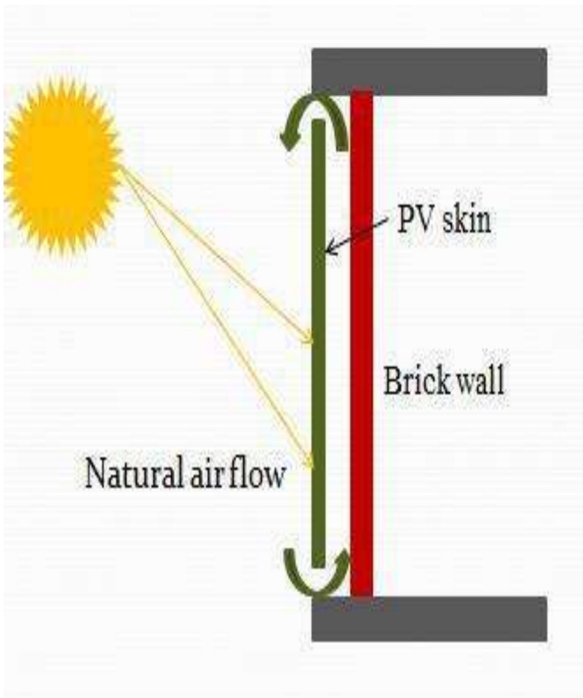

Figure 3.5 South wall with PV and air cavity

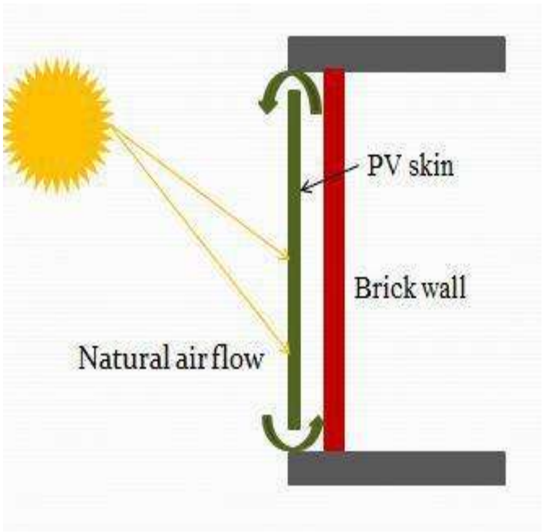

Figure 3.6 South wall with PV and Ventilation

3.2.4 Simulation

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.

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.

3.3 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;

1. Zone Electric Equipment Electric Energy
2. Zone Lights Electric Energy
3. Heating Coil Electric Energy
4. Cooling Coil Electric Energy
5. Zone Air Temperature
6. Zone Packaged Terminal Air Conditioner Electric Energy
7. Site Outdoor Air Dry bulb Temperature
8. Surface Inside Face Conduction Heat Transfer Rate
9. Surface Inside Face Temperature
10. Surface Outside Face Temperature
11. Inverter AC Output Electric Energy
12. Transformer Output Electric Energy
13. All these variables are collected for all configurations as well as for all locations.

4. RESULTS & ANALYSIS

4.1 Composite

First ECBC base (case 1) and all its variations have been simulated in the composite weather condition of New Delhi. The simulation results have been analyzed on annual as well as monthly basis which are as follows;

4.1.1 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 5.1).

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 5.1).

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 not 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.

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 Warm and Humid

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

4.2.1 Annual Results and its Analysis

The annual electrical energy consumption in south zone of the test chamber is 459.06 kWh in lightening, 1123.20 kWh in equipment, 2655.69 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.

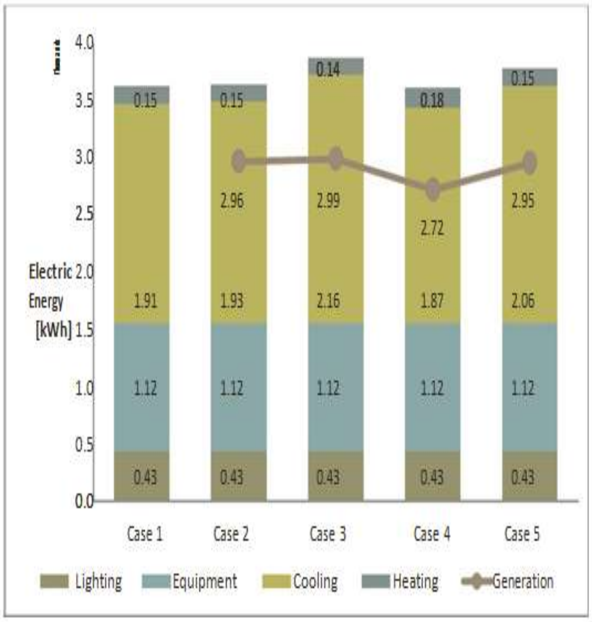

Figure 4.1 Annual electricity consumption and PV generation at New Delhi

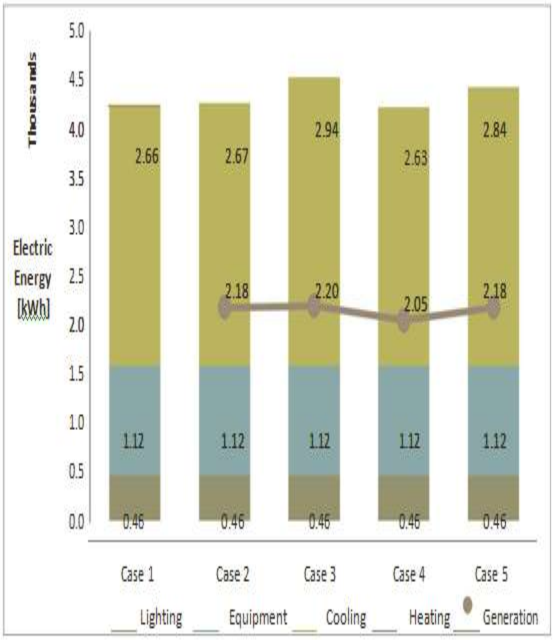

Figure 4.2 Figure Annual electricity consumption and PV generation at Chennai

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 2674.95 kWh. Thus, the total electrical energy consumed by south zone is 4257.21 kWh and generated by photovoltaic is 2176.58 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 2937.26 kWh. The electrical energy generated by photovoltaic is increased to 2195.02 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. 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 2634.98 kWh. The electrical energy generated by photovoltaic is decreased to 2046.24 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 2838.24 kWh. The electrical energy generated by photovoltaic is increased to 2177.41 kWh.

4.3 Hot and Dry

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

4.3.1 Annual Results and its Analysis

After simulating the Base case the annual electrical energy consumption in south zone of the building is 410.58 kWh in lighting, 1123.20 kWh in equipment, 2185.58 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 2210.72 kWh. Thus, the total electrical energy consumed by south zone is 3744.73 kWh and generated by photovoltaic is 3017.07 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 2479.42 kWh. The electrical energy generated by photovoltaic is increased to 3044.27 kWh.

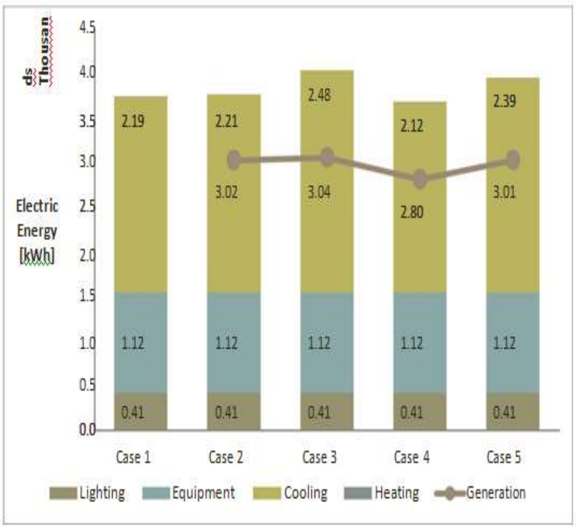

Figure 4.3 Annual Electricity Consumption and PV Generation at Ahmedabad

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 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 2124.08 kWh. The electrical energy generated by photovoltaic is decreased to 2798.85 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 2392.71 kWh. The electrical energy generated by photovoltaic is increased to 3014.47 kWh.

4.4 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;

4.4.1 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.

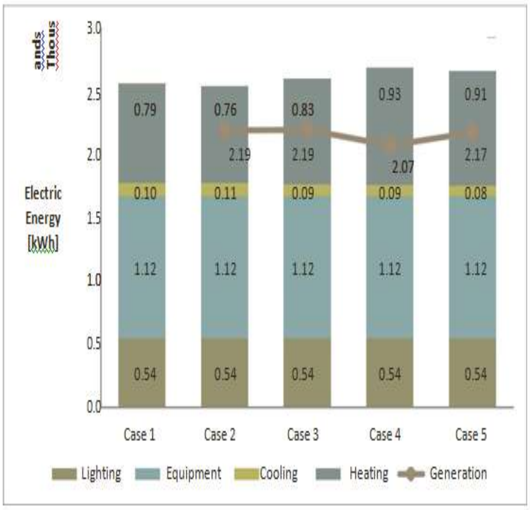

Figure 4.4 Annual electricity consumption and PV generation at Shillong

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 107.25 kWh and in heating is decreased to 763.13 kWh. Thus, the total electrical energy consumed by south zone is 2534.44 kWh and generated by photovoltaic is 2186.98 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 93.46 kWh and in heating is increased to 833.33 kWh. The electrical energy generated by photovoltaic is decreased to 2191.06 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 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 heating is increased to 928.70 kWh. The electrical energy generated by photovoltaic is decreased to 2066.55 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 decreased to 83.52 kWh and in heating is decreased to 905.98 kWh. The electrical energy generated by photovoltaic is increased to 2173.06 kWh.

4.5 Moderate

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

4.5.1 Annual Results and its Analysis

After simulating the Base case the annual electrical energy consumption in south zone of the test chamber is 436.64 kWh in lighting, 1123.20 kWh in equipment, 1616.42 kWh in cooling, and heating is not required.

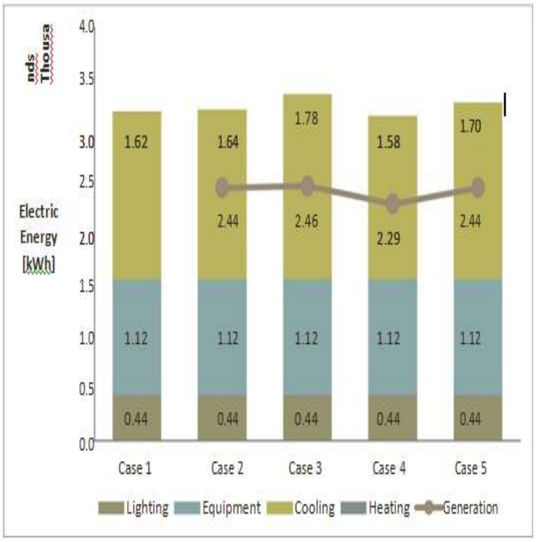

Figure 4.5 Annual electricity consumption and PV generation at Bengaluru

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 equipment and lighting. The electrical energy consumed in cooling is increased to 1637.57 kWh. Thus, the total electrical energy consumed by south zone is 3397.41 kWh and generated by photovoltaic is 2441.56 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 1782.85 kWh. The electrical energy generated by photovoltaic is increased to 2459.69 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 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 1575.82 kWh. The electrical energy generated by photovoltaic is decreased to 2286.80 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 1700.43 kWh. The electrical energy generated by photovoltaic is increased to 2439.80 kWh.

5. CONCLUSION

To simulate the building, first a 3D model has been created in GoogleSketchUP. 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;

5.1.1 Composite

The building model and its various configurations of PV integration on Panels have been simulated in the EP in composite climate of New Delhi. 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.

5.1.2 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 Chennai. 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.

5.1.3 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 Ahmedabad. 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.

5.1.4 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 Shillong. 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.

5.1.5 Moderate

The building model and its various configurations of PV integration on Panels have been simulated in the EP in moderate climate of Bengaluru. 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.

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