# A simulated study of the use of building integrated photovoltaics technology in building envelope retrofit for energy efficiency

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**Abstract**

*Building envelopes play a significant role in enhancing the energy efficiency of the building. With increasing energy demand, the need arises to adopt appropriate technologies and systems to design and retrofit buildings to make them self-sufficient. The paper explores the possibility of combining energy efficiency and renewable energy strategies in building retrofitting. The paper presents a study of the impact of using building-integrated photovoltaics (BIPV) technology for building retrofitting on the energy demand through simulation. Two scenarios are used in the study wherein the skin of an existing building envelope is replaced with building-integrated photovoltaic panels, and the latter is used to generate an appropriate building form at the design stage to harness maximum solar efficiency. The study employs Revit, Rhino, and Ladybug applications to simulate partial retrofit of a building surface of an existing building and generate design alternatives to achieve optimum solar efficiency considering various building parameters. The results determine the advantages of using BIPV panels as an alternative to building facades to achieve robust building performance.*

***Keywords:*** *Building integrated photovoltaics, building retrofit, energy efficiency, building simulation*

## 1. Introduction

Life cycle analysis of buildings reveals that approximately 40% of the energy consumption globally is contributed by buildings, of which India contributes around one-third of the global average [9][10]. Addressing this alarming issue requires the development of energy-efficient building designs that facilitate the minimization of energy consumption, thereby fostering sustainable growth. On a macroscopic scale, buildings in India are rarely designed with a focus on reducing both embodied and operational energy [8].

Hence, energy-efficient building design in India emerges as the most promising option, given that the building sector holds the most significant potential for significantly reducing greenhouse gas emissions.

Building envelopes play a significant role in enhancing the energy efficiency of the building [1][2][3][6]. The building surfaces are exposed to sunlight, and the appropriate design of the building facades with photovoltaic panels can reduce the energy demand of the building [7]. In India, the application of building integrated photovoltaics (BIPV) technology is advantageous due to its geographic location [8][9]. Hence, as a dependable renewable energy source, solar energy holds significant promise in addressing the growing energy demands of Indian urban areas.

The paper explores the possibility of combining energy efficiency and renewable energy strategies in building retrofitting. The paper presents a study of the impact of using building-integrated photovoltaics (BIPV) technology for building retrofitting on the energy demand through simulation. Building envelope retrofit may include aesthetic or structural aspects, but these aspects do not consider the rising demand for building energy efficiency [1]. Hence, two scenarios are studied: one wherein the skin of an existing building envelope is replaced with building-integrated photovoltaic panels, and the latter is used to generate an appropriate building form at the design stage to harness maximum solar efficiency. The study employs Revit, Rhino, and LadyBug applications to simulate partial retrofit of a building surface of an existing building and generate design alternatives to achieve optimum solar efficiency considering various building parameters. This comparative analysis is to conclude the feasibility of both alternatives.

## 2. Literature Review

Retrofitting a building refers to modifying a completed building to enhance performance [4][5]. Building envelope elements, including roof, wall, fenestrations, and their characteristics are studied during the process to enhance the energy performance of the building [4]. The vertical envelope of the building includes a substantial surface area, which is often neglected while integrating the energy performance of the building. Building facades have massive potential for the installation of photovoltaics [6]. Building integrated photovoltaic system is an advanced technology where photovoltaics are integrated into the building façade or roof to generate clean energy. BIPV systems contain PV modules that replace conventional building materials and power generators used in building envelopes, which reduce incremental and life-cycle costs and are cost-effective compared to other systems [2][3].

The present study conducted a systematic building performance simulation process wherein a virtual model of the building sample is constructed to determine the best retrofit possibility through predictive performance simulations. Building performance simulation (BPS) is conducted in three phases. The first phase is known as Building energy auditing, wherein the building is evaluated for the current energy consumption.

The second phase is the development of retrofit strategies, which involves adopting all sustainable features when considering the design alternatives to be generated. The final step is the simulated implementation of retrofitted elements through the simulation of the building envelope to improve the overall energy performance of the building. The present study focuses on building envelope energy retrofit using renewable energy generation resources by combining the energy retrofit strategies of building envelopes and using BIPV technology to improve the buildings' energy performance.

## 3. Methodology

The study is carried out using building performance simulation procedure. The study is divided into two phases. The first phase considers an existing institutional building and simulation is done to understand the advantages of application of BIPV systems on to the skin of the existing building. The second phase is a condition where a new built form is developed on the same site conditions along with BIPV systems and analyzed for the efficacy of the building for energy efiiciency. Figure 1 explains the methodology of the study.

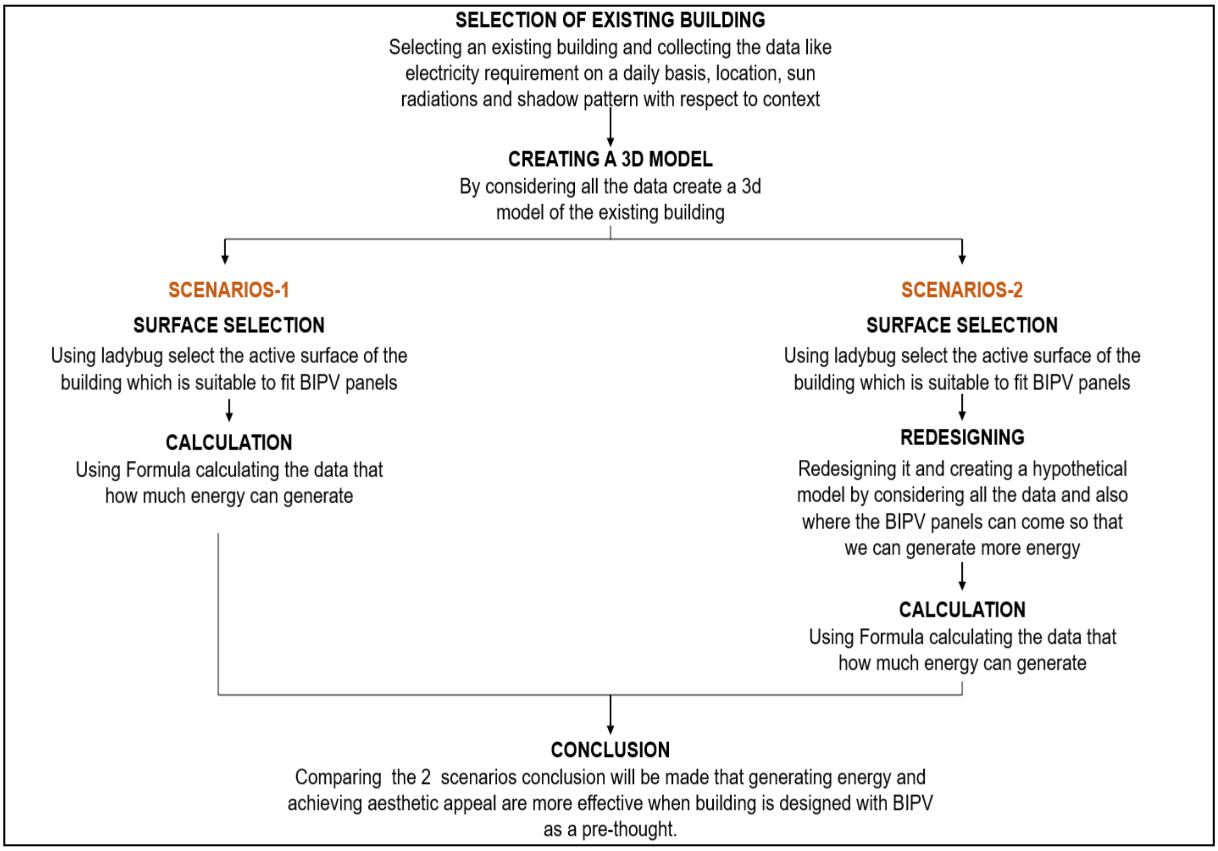


**Figure 1. Study Methodology**

### 3.1 Site Selection

The study's criteria for choosing the building included exposure to solar radiance during the day, being affected least by shadows, geographic location, building orientation, and climatic conditions. The building chosen for the study is located on an institutional campus of Siddaganga Institute of Technology, Tumakuru. The building is a four-story RCC structure of 950 sq.m. ground coverage. Figure 2 indicates the location of the building sample chosen for the study. The energy consumption was recorded for seven days at 296.76 kWh.

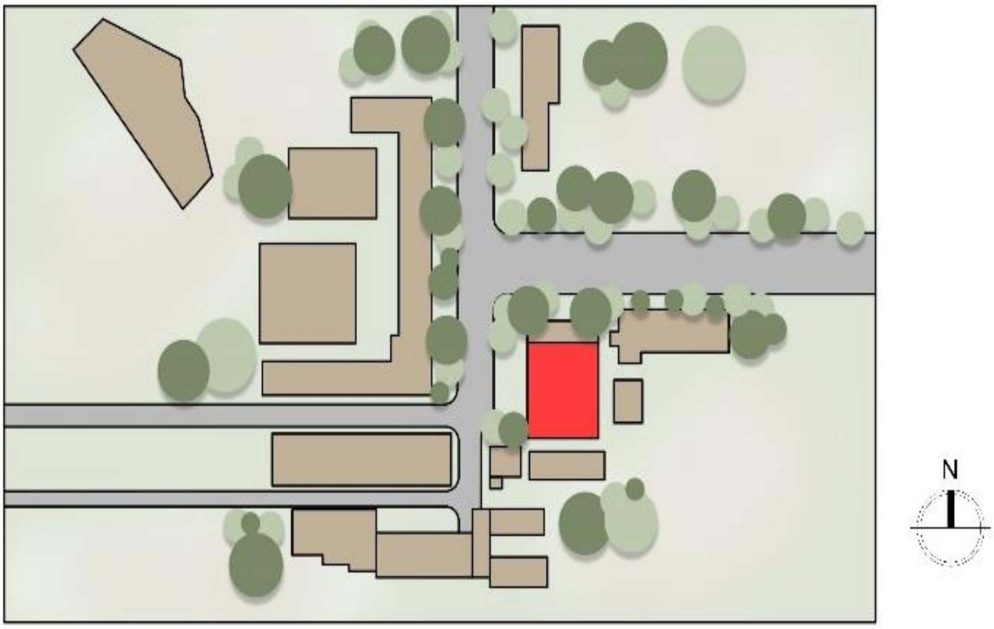


**Figure 2. Building location**

### 3.2 Model generation

A comprehensive and intricate 3D model was created using Revit software, a building information modeling (BIM) tool. This detailed model was crucial for performing subsequent direct sunlight simulations, wherein the software's capabilities are utilized to simulate and analyze the impact of direct sunlight on the specified structure or environment. These simulations provided valuable insights into how sunlight interacts with the elements of the model, aiding in the assessment of factors such as shading, daylighting, and overall solar exposure. The elaborate 3D model is a foundation for conducting precise and insightful analyses, contributing to a thorough understanding of the project's response to direct sunlight conditions. Figure 3 shows the exisiting plan and the 3D model developed using Revit software.

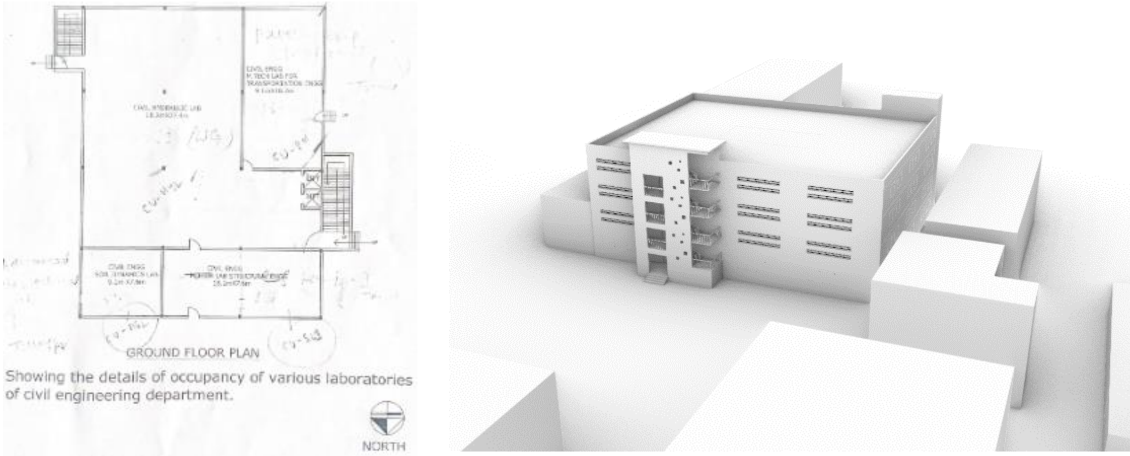


**Figure 3. Plan and 3D view of the building**

### 3.3 Simulation

The 3D model generated in Revit is put for direct sunlight simulation using Rhino and Ladybug. Two scenarios were created according to the study objective, and the analysis was carried out. The formula for calculating the total energy generated by the solar panels is expressed as Energy = Panel Size × Panel Efficiency × Solar Irradiance × Daily Sunlight Hours. The standard panel size was 1m x 2m, and 72 cell panels were installed.

## 4. Results and discussion

Scenario 1 was to replace the building surface with a BIPV system and calculate the energy generated. The results indicate that the roof area receives maximum sunlight 12 hours a day, while the southwestern facade is exposed to sunlight for 10.8 hours daily. The total area of the panel was 450m² with 20% panel efficiency and 5.4 kWh/m²/day solar irradiance. Daily sunlight hours were considered to be 10.8 hours on average. Hence, the total energy generated was 5248.8 kWh. Figure 4 shows the simulation carried out in Ladybug.

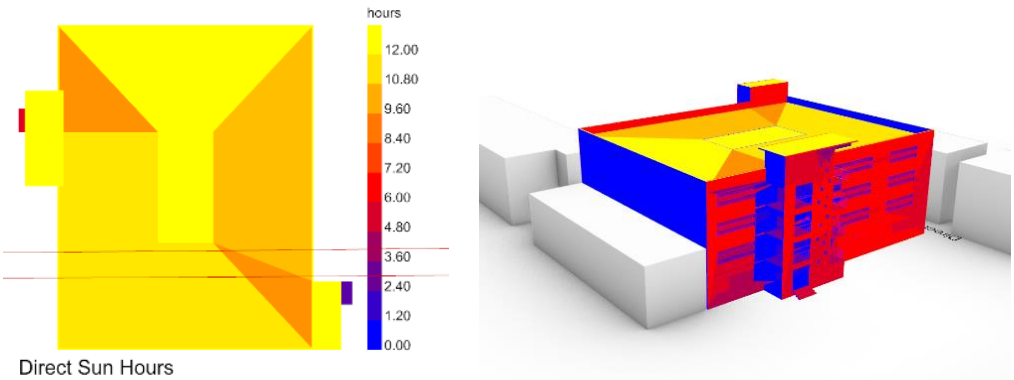


**Figure 4. Simulation model of the existing building**

Scenario 2 considered that the southwest facade receives more heat, as determined in the scenario one analysis. So, In the process of redesigning the building, a deliberate and strategic approach has been adopted to enhance the utilization of solar energy. The procedure included a thoughtful allocation of increased space, specifically on the southwest facade, aimed at maximizing the installation of solar panels. The redesign emphasized a keen understanding of the sun's path and intensity, ensuring that the designated area receives optimal sunlight exposure. Moreover, the shading devices incorporated into the redesign are intricately designed to provide adequate protection against excessive heat and glare on the southwest facade. The meticulous planning extends to the positioning and orientation of these shading devices, further enhancing their efficiency in mitigating solar heat gain. This careful consideration reflects a commitment to harnessing renewable energy sources while simultaneously addressing the climatic challenges associated with the building's location. The result is a redesigned building that optimizes solar panel efficiency and prioritizes sustainable and energy-efficient practices in its overall architectural strategy. Figure 5 shows the redesigned model used for simulation. The redesigned 3D model generated in Revit is put for direct sunlight simulation using Rhino and Ladybug. The results indicated that the total energy generated was 10011.6 kWh.

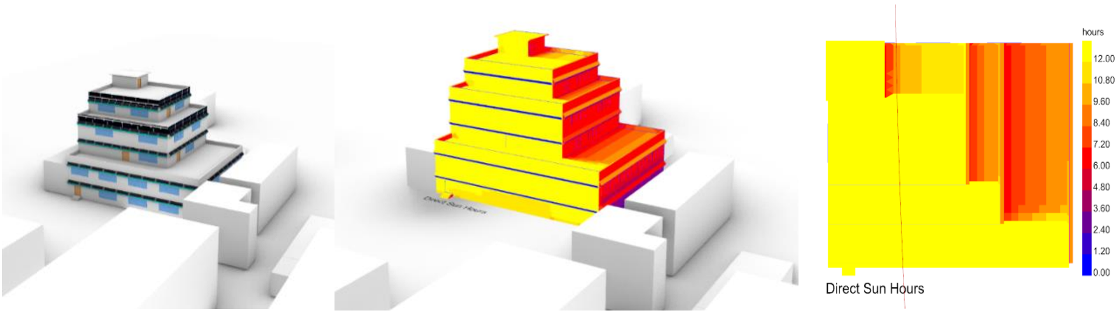


**Figure 4. Simulation model of the existing building**

Comparing the results obtained, scenario one, where the partial surface was replaced with BIPV systems, proved to meet the energy demand and make it self-sufficient. Further, through scenario two, where a conscious attempt was made to redesign the building volume to harness more solar energy, the results suggest that the design evolved into a solar-positive design.

## 5. Conclusion

The present study presents a simulated study of building retrofit with a BIPV system. Considering the sustainable aspects of BIPV systems, the study also proves that buildings with smaller roof areas can use this technology and become energy-efficient buildings. The study also suggests that BIPV panels can be used as an alternative façade solution to generate balance in the energy demand of the building without compromising on aesthetics. Furthermore, the simulation of a solar passive built-form design in the same context determines that applying BIPV panels may result in a solar-positive design.

The scope of the study is limited to a single scenario in a hot and dry climatic zone of India, with fewer shadows around the building. The scope of the study may be extended to various scenarios to test the efficiency of BIPV panels for retrofitting buildings in the Indian context. The study assumes the energy demand of the building during seven days of the winter season. Thus, the study may be extended to recording the year's demand and comparing it with the energy generated throughout the year for a comprehensive understanding of the system and its advantages. Hence, BIPV is a promising technology that can potentially reduce the energy crisis across the country and is also a justifiable means for CO2 emission reduction, thus escalating sustainable development.

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