BIPV prototype for the solar insolation calculation

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Purpose Renewable energy components such as Building Integrated Photovoltaic (BIPV) often influence the aesthetic quality of a building adversely and hence need to be analyzed for their impact on building form and aesthetics. This becomes crucial especially in the case of a sun-tracking photovoltaic system. Moreover, there is a need to propose a reasonably accurate but quick system to estimate the amount of solar insolation received by a given location. Both the visualization of BIPV's movement and the solar insolation calculation can be integrated into a Building Information Model (BIM) to help design professionals to assess the feasibility of various solar photovoltaic options. **Method** A solar insulation model proposed by Kumar and Umananda is used to develop a BIPV prototype in a BIM platform (Autodesk Revit). A graphical user interface is developed to input the time and location information. **Results & Discussion** A BIPV-prototype is developed to calculate solar position and determine the amount of solar insolation from given time and location information. The proposed model can be integrated into BIM to automatically calculate the solar position and the amount of solar insolation based on user inputs of time and location. We plan to compare this prototype with PV F-chart method. We will also research the use of Modelica for creating PV-component models and integrating the PV-modeling into thermal and daylight modeling.

Keywords*: information technology, BIM, solar insolation, clearness index, BIPV*

INTRODUCTION

Among current trends in architectural design is to introduce sustainability by either applying energy saving strategies or incorporating renewable energy options. One dilemma faced by building designers is to create a balance between aesthetics and technology. One among most practiced is the Building Integrated Photovoltaic (BiPV) that involves integrating solar cells or modules into the building components such as walls, canopies, roofs etc.[1, 2]. Studies suggested that BiPVs not only facilitate generating renewable energy but also, protect buildings from heat, cold and rain[3]. Furthermore, BiPVs may be more cost effective if they replace building components such as wall cladding panels, roof slates, light shelves, sun-shades etc. Renewable energy components such as solar photovoltaic (PV) panels often influence the aesthetic quality of the building adversely and hence, need to be analyzed for their possible impact on building form and aesthetics. Studies[3, 4, 5] suggested considering both technological and aesthetic factors while integrating such renewable technologies into a building.

The maximum power conversion efficiency of a typical solar module (monocrystalline) is 14-17%[5] and hence; maximizing its power would require optimizing PV orientations over daily sunshine hours. This may be possible by designing and installing sun-tracking BiPV modules that are integrated into a building as building components such as roof tiles. For a better understanding of the orientation of a sun tracking solar module at a given time it becomes important to visualize their movement throughout the day. Furthermore, it is also important to make sure that these panels do not cast shadows on each other[2].

The solar insolation data become crucial for analyzing solar PV applications for economic and functional feasibility. The insolation data can be either measured at a given location or can be procured from a meteorological agency both of which could be expensive and time consuming[6]. According to Kumar and Umananda[6], for a widespread application of Solar PV system, a straightforward and quick method to calculate the global solar insolation at any given location is crucial.

This paper focuses on developing a BiPV prototype by integrating an Application Programming Interface (API, of Autodesk Revit as a sample BIM platform) into a BIM for calculating the orientation of a sun-tracking PV roof tile/panel. In addition, the solar insolation model proposed by Kumar and Umananda[6] is used to develop a mathematical model for calculating direct global solar insolation in North America. In the future, this model will be added to the BiPV prototype developed in Autodesk Revit.

OBJECTIVES

The research is aimed at, developing a BiPV prototype to calculate the orientation of sun-tracking solar PV roof tiles/panels and validating the model proposed by Kumar and Umananda[6] for locations in North America. The following are the main objectives:

- To develop a BiPV prototype in a BIM platform (Autodesk Revit) to calculate the solar orientation
- To develop and validate the global solar insolation (direct component) model for locations in North America

RESEARCH METHODS

A parametric family for the sun-tracking solar PV roof tiles is developed and integrated into a generic residential building model in Autodesk Revit. The orientation of solar PV roof tile is governed by solar altitude and azimuth angles. The altitude and azimuth angles can be calculated using the latitude, longitude, time and day information. An API is developed and integrated into the parametric family to perform the solar altitude and azimuth angle calculation. A graphical user interface helps the user in entering latitude, longitude, time and day information. The API performs the calculation and sets the calculated values to the altitude and azimuth of the parametric family to show the solar orientation.

The extraterrestrial direct solar insolation can be calculated for a given location and time. The actual amount of direct global insolation received at a location depends upon a stochastic parameter called the sky clearness index, which is a function of time and geographic location. The seasonal and climatic conditions vary with time of the year and geographic location and affect the value of clearness index. The solar insolation model proposed by Kumar and Umananda[6] is based on the latitude, precipitable water vapor in the atmosphere and day of the year data. Such information is easily available for most of the locations around the world[6]. The measured values of sky clearness index are used to calculate Fourier coefficients that help curve fit the plot of clearness index versus the day of the year. Kumar and Umananda[6] developed and validated the model for locations in India between 0-32 degrees (North) latitudes.

We developed and validated a mathematical model using the same approach for North American locations between 0-32 degrees (North) latitudes. Table 1 provides the list of twelve locations with latitude information that are used in developing the model. The measured values of sky clearness index, precipitable water vapor and global insolation are sourced from the NASA Surface Meteorology and Solar Energy website[7]. Three locations other than the ones included in the model development are selected in the United States of America for validation.

FINDINGS

Figure 1 illustrates the parametric solar PV roof tile family developed in Autodesk Revit. A graphical user interface (as shown in Figure 1) collects the latitude, longitude, time and day information and calculates the solar orientation. It also modifies and shows the position of solar PV roof tiles based on the calculated altitude and azimuth values.

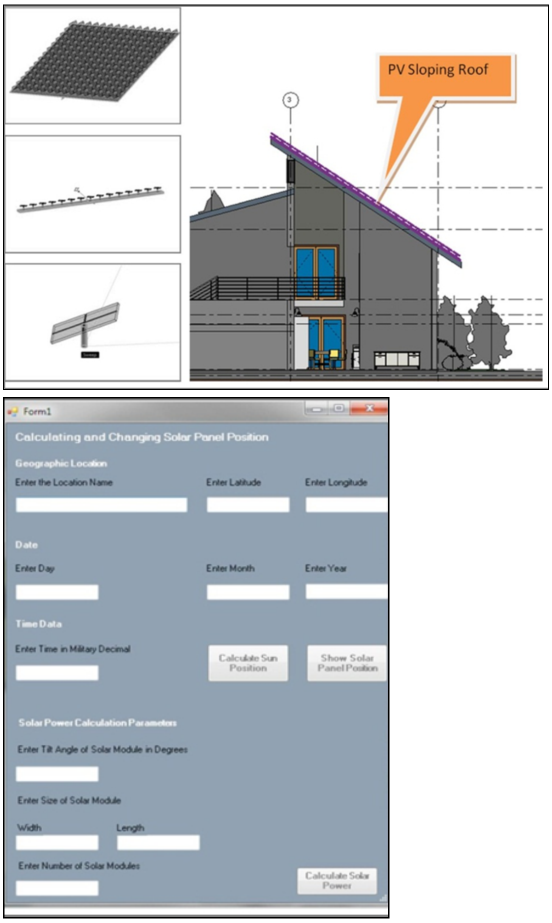

Fig.1. Parametric solar PV roof family (Autodesk Revit) and the graphical user interface

Table 1. Twelve locations (North America) used in model development

Location	Latitude
Panama City, Panama	8.97
Guatemala City, Guatemala	14.62
Mexico City, Mexico	19.43
Hilo, HI, USA	19.72
Durango, Mexico	24.017
Brownsville, TX, USA	25.9
Naples, FL, USA	26.13
Laredo, TX, USA	27.53
Orlando, USA	28.4
San Antonio, USA	29.42
New Orleans, USA	29.95
Albany, GA, USA	31.53

The mathematical model for calculating the direct global solar insolation is validated for three locations in the United States of America namely Jacksonville (Florida), Dallas (Texas) and Brunswick (Georgia). Table 2 provides the measured and calculated values of sky clearness index and direct global insolation on horizontal surface. The Measured values are monthly averaged values (22 year's average) sourced from the NASA website[7]. Figures 2, 3 and 4 illustrate the measured and calculated direct global insolation for 12 months for the three locations. It can be seen that the calculated direct global insolation values are within 0.18 – 9.22 % of the monthly averaged measured values. Such error is reasonable for the preliminary assessment of a solar PV system for a given location.

Table 2. Calculated (K_{cal}) and measured (K_{meas}) values of sky clearness index at locations of validation

Month	Jacksonville		Dallas		Brunswick	
	K_{cal}	K_{meas}	K_{cal}	K_{meas}	K_{cal}	K_{meas}
Jan	0.69	0.7	0.69	0.72	0.69	0.7
Feb	0.69	0.71	0.7	0.73	0.7	0.71
Mar	0.7	0.7	0.7	0.73	0.7	0.7
Apr	0.69	0.7	0.68	0.7	0.69	0.69
May	0.66	0.66	0.66	0.68	0.66	0.66
Jun	0.64	0.63	0.64	0.65	0.64	0.62
Jul	0.62	0.62	0.64	0.64	0.63	0.61
Aug	0.63	0.63	0.64	0.63	0.63	0.62
Sep	0.64	0.65	0.65	0.67	0.64	0.64
Oct	0.67	0.66	0.67	0.69	0.67	0.67
Nov	0.69	0.68	0.7	0.71	0.69	0.68
Dec	0.69	0.69	0.7	0.71	0.7	0.69

Table 3. Calculated (In_{cal}) and measured (In_{meas}) values of direct global insolation (KWh/m^2) at locations of validation

Month	Jacksonville		Dallas		Brunswick	
	In_{cal}	In_{meas}	In_{cal}	In_{meas}	In_{cal}	In_{meas}
Jan	4.05	4.13	3.75	4.01	3.92	4.01
Feb	5.07	5.11	4.77	5.09	4.91	5.05
Mar	6.23	6.26	5.94	6.34	6.06	6.12
Apr	7.18	7.2	6.92	7.19	7	7.13
May	7.56	7.39	7.33	7.59	7.36	7.37
Jun	7.72	7.28	7.42	7.58	7.33	7.18
Jul	7.64	7.03	7.26	7.31	7.06	6.95
Aug	7.16	6.64	6.69	6.64	6.59	6.51
Sep	6.21	6.04	5.83	6.16	5.87	5.94
Oct	5.14	5.15	4.85	5.18	4.98	5.09
Nov	4.18	4.26	3.96	4.22	4.11	4.15
Dec	3.75	3.77	3.49	3.67	3.67	3.68

CONCLUSIONS

An API was developed and integrated into a generic residential model built in Autodesk Revit to calculate and show the orientation of sun-tracking solar PV roof tiles. It is found that the movement of solar PV tiles can be accurately modeled using a parametric family in BIM. Such a tool can help architects and design professionals to visualize the orientation of solar PV tiles to balance the aesthetics and technology in architectural design. We also developed and validated a solar insolation model based on the method derived by Kumar and Umananda[6]. It was concluded that such mathematical model can calculate the sky clearness index and direct global insolation in a given location with a ±10% error (over measured data). The model utilized easily available information such as latitude and precipitable water vapor in the atmosphere to compute the direct component of global solar insolation.

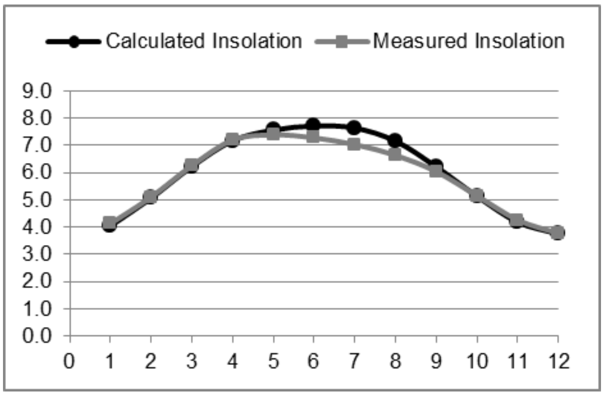

Fig.2. Direct component of global solar insolation (KWh/m2) at Jacksonville, FL, USA

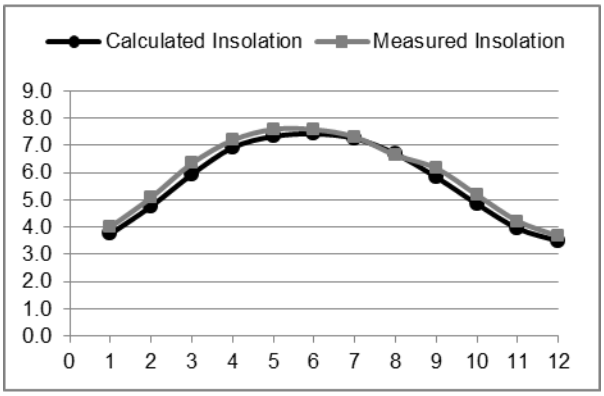

Fig.3. Direct component of global solar insolation (KWh/m2) at Dallas, TX, USA

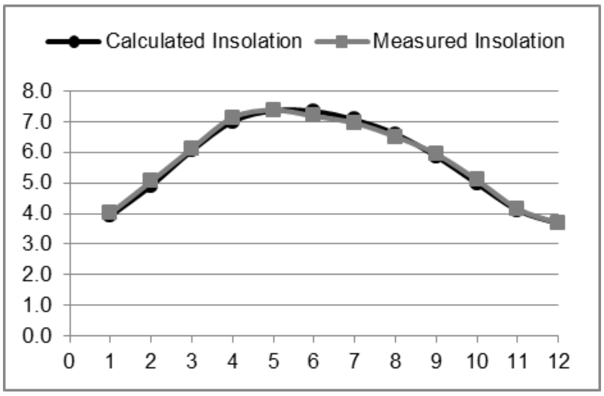

Fig.4. Direct component of global solar insolation (KWh/m2) at Brunswick, GA, USA

FUTURE RESEARCH

We plan to integrate the developed solar insolation model into BIM so that not only the solar orientation but also the amount of solar insolation can be calculated with a reasonable accuracy (error within 15% of the measured values). Moreover, a model for other latitudes will also be developed and validated to extend the scope of API to other locations around the globe. We also plan to include the calculation of diffused and scattered component of the global insolation in the proposed model.

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