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Influence of Shading on a BIPV System's Performance in an Urban Context: Case Study of BIPV Systems of the Science Center of Complexity Building of the National and Autonomous University of Mexico in Mexico City

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***Abstract*—**The purpose of this paper is to establish the influence of shading on a Building Integrated Photovoltaic (BIPV) system´s performance in an urban context. The PV systems of the Science Center of Complexity (Centro de Ciencias de la Complejidad) Building based in the Main Campus of the National and Autonomous University of Mexico (UNAM) in Mexico City was taken as case study. The PV systems are placed on the rooftop and on the south façade of the building. The south-façade PV system, operating as sunshades, consists of two strings: one at the ground floor and the other one at the first floor. According to the building's facility manager, the south-façade PV system generates 42% less electricity per kilowatt peak (kWp) installed than the one on the roof. The methods applied in this study were Solar Radiation Analysis (SRA) simulations performed with the Insight 360 Plug-in from Revit 2018® and an on-site measurement using specialized tools. The results of the SRA simulations showed that the shading casted by the PV system placed on the first floor on top of the PV system of the ground floor decreases its solar incident radiation over 50%. The simulation outcome was compared and validated to the measured data obtained from the on-site measurement. In conclusion, the loss factor achieved from the shading of the PVs is due to the surroundings and the PV system´s own design. The south-façade BIPV system's deficient design generates critical losses on its performance and decreases its profitability.

***Keywords*—**Building integrated photovoltaics (BIPV) design, energy analysis software, shading losses, solar radiation analysis.

I. Introduction

CLIMATE change and global warming are two of the main challenges that our planet is facing [1]. In Mexico, 19% of the greenhouse gases are produced because of electricity generation, therefore promoting the use cleaner energy sources [2]. The use of renewable energy sources for electric power generation is increasing as pointed out in the 2014 National Energy Balance of the Secretariat of Energy in Mexico[1] [3]. The solar energy has an electric energy generation potential of 6,500,000 GWh, a hundred times greater than the rest of the clean energy [4]. The most commonly used solar power generation technology in Mexico is the PV systems [5].

With the purpose of promoting the use of renewable energies, the UNAM has PV systems installed in different buildings within the University City[2] in Mexico City. Two PV systems are installed on the Science Center of Complexity Building of the UNAM[3] (C3-UNAM). The first system is placed on the rooftop of the building and has 90 PV panels. The second system is installed on the southern façade. The on-site energy generation is one of its purposes. The PV system also functions as solar control devices, due to the elevated levels of solar radiation of the exposed southern façade of the building [6]. Both systems use polycrystalline silicon technology.

Based on a previous study carried out on last May 2016 by students of the Master´s and Doctoral Program in Architecture at the C3-UNAM, it was observed that some of the components of the PV panels' system on the southern facade reached temperatures over 60 °C during May. It was also seen that the panels located on the upper floor level casted shadow over the panels installed on the ground floor level [6]. The report did not analyze the effects of these conditions on electric energy generation. Therefore, this paper examines if the shading condition is affecting the performance of the installed PV panels and reducing their efficiency.

In Fall 2016[4], an early solar analysis performed to the C3-UNAM Building allowed to observe that the two systems (the one on the rooftop and the one on the façade) have similar conditions: orientation, tilt angle, ambient temperature, wiring, maintenance and maximum power of the system. The loss factor in BIPV systems due to the shading effect is critical, and this should be analyzed and avoided since its early design stage. Therefore, it is assumed that a factor that is producing the difference in power generation between the two systems is the shading. The purpose of this paper is to analyze how shading affects the performance of the PV system installed on

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[1] Original in Spanish: Secretaría de Energía

[2] Original in Spanish: Ciudad Universitaria

[3] Original in Spanish: Centro de Ciencias de la Complejidad de la UNAM

[4] In the course "Interaction with the Environment. Thermal Aspects" in the Master's and Doctoral Program in Architecture of the School of Architecture at the UNAM taken by the corresponding author and taught by the co-author.

the southern façade of the C3-UNAM Building by comparing the estimated power obtained from computer simulations with the measured power data provided by the building's facility manager [7].

II. Literature Review

A. Generation of Electrical Energy from the PV Effect

Solar cells directly transform solar energy into electrical energy. The process of generating electrical energy starts from the materials from which the cell is made (semiconductors) that absorb part of the solar radiation that falls on them and transform it, with greater or lesser efficiency, into electrical energy. When a solar cell is connected to an electrical load and illuminated, a potential differential is generated in that load, so a current will flow through it [8].

The photoelectric effect, which was found in the literature reviewed, is the basis of the generation of electrical energy from light. There are two types of photoelectric effects: the internal and the external [9]. However, this paper follows the idea of the PV effect as the basis of the conversion from sunlight to electric energy. This effect occurs when sunlight reaches a PV cell and produces enough energy to release some electrons. Then, a built-in-potential barrier that acts on the electrons produces a voltage that generates a current that can be directed through a circuit [10]. Although the internal PV effect performance ratio is 100%, the performance ratio of a solar cell is much lower due to different loss factors that are reviewed later [8].

There are three characteristics about the solar cells identified from the literature review: 1) the type of material that is made from (i.e., silicon is the most common one), 2) the type of technology (i.e., the monocrystalline, polycrystalline and thin films), and 3) the type of connection (i.e., in series or in parallel) [8].

The series connection allows increasing the voltage levels of the cells, while the values of generated current can be increased by means of the parallel connection [8]. In order to achieve the voltage and the current values required for a given application, the solar cells are interconnected and encapsulated which constitutes a module or a PV panel.

B. Electrical Parameters and Loss Factors of PV Systems

The two main electrical parameters of a PV module are the peak power and the energy yield. The peak power is the maximum power the PV module can generate under standard conditions[5]. The energy yield ratio is the quotient between the maximum power and the luminous power received by the module [8].

The energy yield ratio of a PV panel is always below 100% and depends on the technology used (See Table I). The silicon is the most common and commercial technology used in PV, due to its high performance and reliability [8].

The total power generated by a PV system requires two elements: 1) the product of the irradiance multiplied by its nominal performance and 2) the series of loss factors that modify the product of the irradiance multiplied by its nominal performance: The quotient between the generated power and the estimated maximum power[6].

TABLE I
Energy Yield Ratio of PV Panels according to Technology Used [8], [9], [11]

Technology	Typical yields (%)
Monocrystalline silicon	12-15
Multicrystalline silicon	11-13
Opaque amorphous silicon	5
Semi-transparent amorphous silicon	4
Cadmium Sulfide CdS	5-8
Gallium arsenide	16-20
Edge-defined film-fed growth (EFG) cells	11-13

The loss factors identified from the literature review are the next ones: by annual irradiance, by temperature, by dispersion or mismatch, by wiring and connections, by dirt, by shading, by reflection and by radiation spectrum. These factors affect the PV systems with different intensity (see Table II).

TABLE II
Typical Minimum and Maximum Values of Energy Loss in PV Systems Interconnected to the Electric Grid [12]

Energy loss factors	Typical yields (%)
Temperature	5-45
Angular reflection and radiation spectrum	0.5-7
Tolerance and degradation	2-5
Shading	0-5
Dirt	0.5-4.5
Mismatch	2-4
Low irradiation	0.5-3
Ohmic value	0.5-1.5

III. Methodology

In order to understand the impact of the shadow casted over the ground floor panels, the methods used in this study were an empirical evidence experiment and a solar energy computer analysis.

Firstly, the measured data and information regards the PV systems were provided by Architect María Teresa Gómez Herrera [7], which is the building's facility manager. After receiving and studying these documents, it was observed that both PV systems have similar characteristics such as: location, orientation (azimuth), tilt angle, incident solar radiation, PV panel technology and peak power. Due to this observation, the electrical energy of both systems was compared to determine the shading influence over the ground floor panels performance attached to the southern façade.

A series of solar radiation simulations with the Insight 360 Plug-in for the Revit® 2018 software were run to explain the effects of the shading of the PVs. This Plug-in was used because of its friendly-user interface and the capability to run incident solar-radiation analysis over the surface of the PVs. It also uses the data from the closest weather station to the

[5] Irradiation: 1000 W/m², temperature: 25 °C, AM: 1,5.

[6] Estimated with the PV array nominal power and the incident solar irradiance.

building modeled in Revit® 2018. This is suitable to execute parametric runs of the PV systems.

Finally, the computer simulation results were compared and validated to the on-site measured data obtained from the empirical evidence experiment carried out at the "J" Block Section´s rooftop of the University Postgraduate Unit Building. This is located 0.31 miles (0.5 km) away from the C3-UNAM Building[7] (Fig. 1).

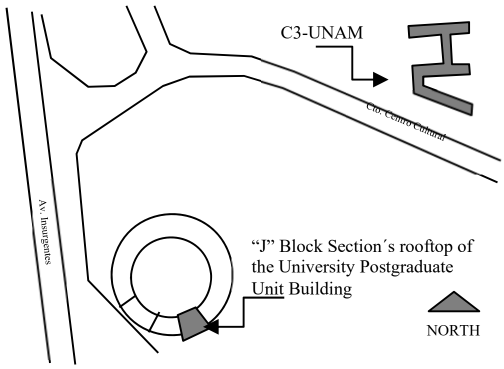

Fig. 1 Location of C3-UNAM and "J" Block Section´s rooftop of the University Postgraduate Unit Building

A. The Building's PV Systems Analysis

The PV systems are installed in the C3-UNAM Building at the University City that is located at 19° 18'N and 99° 10'W and has an altitude of 6,991.5 ft [2,131 meters (meters above sea level)]. These were installed in February 2016. The opening of the C3-UNAM Building´s facilities took place in March 2016.

Both systems are grid-connected and have a monthly preventive maintenance, which consists of components´ overall review and cleaning. Regarding the models´ technical data specifications, both use Solartec® PV panels´ S60PC model (Fig. 2) with different nominal performance values and polycrystalline silicon technology [13].

Fig. 2 Solartec® PV Panels´ S60PC Model [13]

The system located on the rooftop of the building (Fig. 3) has 92 modules with a capacity of 240 Wp[8] and a total capacity of 22 kWp[8] facing south (180°) with a tilt angle of 20°. On the other hand, the system located on the southern facade of the building (Fig. 4) consists of 80 modules with a power of 250 Wp and a total power of 20 kWp facing south with 9 degrees deviated to the west (189°) and a tilt angle of 20°.

Fig. 3 Photography of the C3-UNAM Building rooftop PV System, University City. Image by Viridiana Ardura Perea

Fig. 4 Photography of the South Façade of the C3-UNAM Building, University City. Image by Viridiana Ardura Perea

B. Electric Power Generation

Table III shows the power generated per kWp installed on the analyzed building. This table has the following data: PV system location (first column), number of modules (second column), peak power (third column), total power (fourth column) and power generated by kWp (fifth column).

TABLE III
POWER GENERATED PER KWP INSTALLED ON THE C3-UNAM BUILDING

PV System	Number of modules	Peak Power (kWp)	Total Power (kWh)	Power generated by kWp
Southern Façade	80	20	6,564.36	328.21
Rooftop	92	22	12,438.50	565.38

According to the C3-UNAM facility manager´s report, the PV system located on the rooftop generated 12,438.6 kWh from May to September of 2016. The southern façade panels, despite having similar characteristics to the rooftop panels, reached 6,564.4 kWh. If the electrical energy generated per installed kWp is compared, the southern PV facade barely harvests 58% of the energy that the roof system produces. Thus, it is assumed that the difference of the solar energy transformed between both systems is caused by the shading conditions over the ground floor panels

C. Solar Resource Experimental Analysis

The C3-UNAM Building model was created in Revit® with its building orientation and geometry, local weather, and the location and characteristics of its integrated PV systems (Fig. 5).

[7] Original in Spanish: Edificio J de la Unidad de Posgrado."
[7] Wp= Watt Peak
[8] kWp= Kilowatt Peak

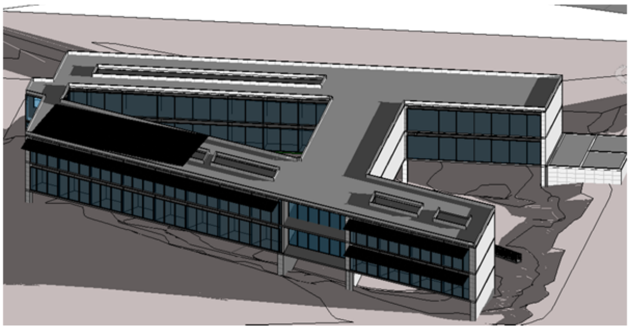

Fig. 5 3D Model of the Complexity Science Center Building (C3-UNAM) with Revit® 2018. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

The conditions of the PV system installed on the rooftop of the C3-UNAM were reproduced in the experiment at the "J" Block Section´s rooftop of the University Postgraduate Unit Building. A KIMO® SL 200 solarimeter model (Fig. 6) was placed over a wooden element that replicates a PV panel oriented directly to the south (180°) with a tilt angle of 20° above the horizon to replicate the C3-UNAM Building PV systems' conditions (Fig. 7). The measurements were taken from October 31st, 2016 at 3:14 p. m. to November 3rd, 2016 at 4:09 p. m.

The simulation was run on November 1st and November 2nd, 2016 from sunrise to sunset (Fig. 8) through Revit® 2018 in order to validate the data. Then, the Revit® 2018 simulation results of the C3-UNAM were compared to the measured data of the experiment at the "J" Block Section´s rooftop of the Postgraduate Unit Building for the same days (November 1st and November 2nd, 2016).

Fig. 6 KIMO® Solarimeter SL 200 Model [14]

Fig. 7 On-site Solar Radiation Measurement Experiment on the Roof of the Building of the Graduate Unit, University City. Image by Viridiana Ardura Perea

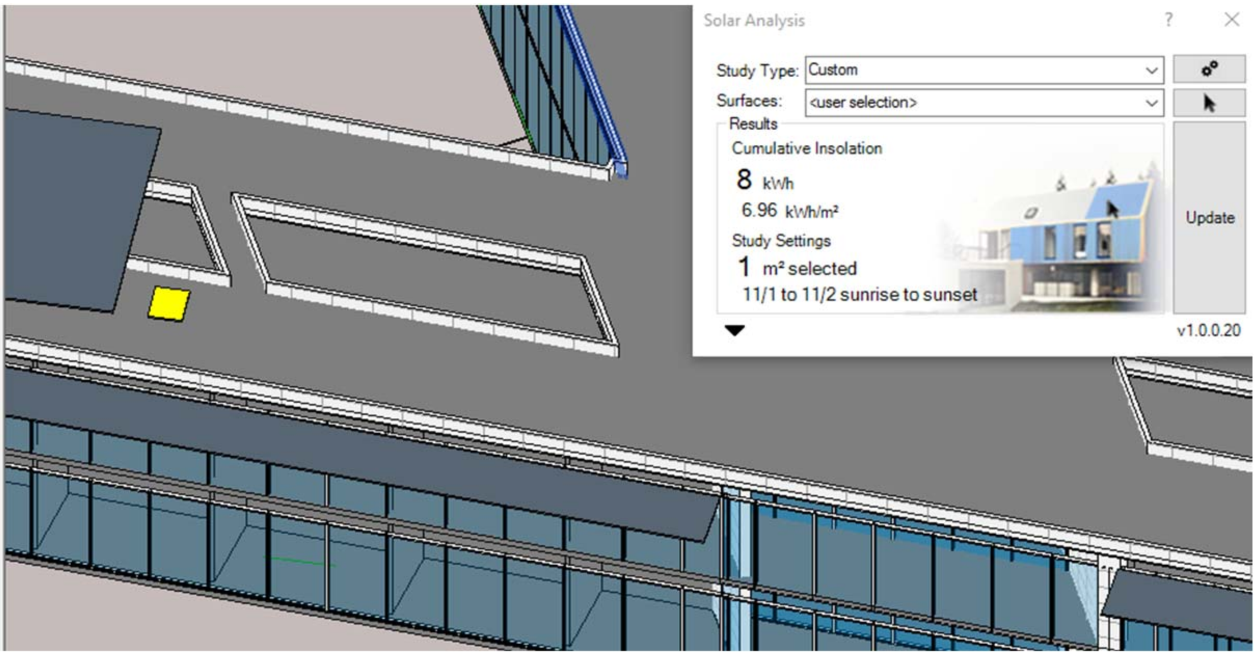

Fig. 8 Computer Simulation of Incident Solar Radiation in the PV System of the Roof of the C3-UNAM Building from November 1st to November 2nd, 2016 with the Insight 360 Revit® 2018 Plug-in. Image created by Viridiana Ardura Perea

IV. Results

A. Computer Simulation Results of the Loss Factor by Shading

The Insight 360 simulations showed the incident solar radiation decrease due to the shading casted by the southern façade-first floor panels over the southern façade-ground floor panels´ catchment surface.

The time length of the simulations was proposed from May 11th, 2016 to September 30th, 2016 to match the same time length and get the same power data provided by the building´s facility manager. The current location of the building was assigned into Revit® 2018 through its geographical coordinates, to obtain the climatological data of the nearest meteorological station (station 1012478).

The following results and observations were obtained from the preliminary runs:

1) For the first simulation test, the panels were inserted to the model as a "family" from the Revit® 2018 existing library. However, the measures of these predefined models did not correspond to the existing building panels.
2) For the second simulation test, a new "family" of PV panels was created with the proper measures and placed instead of the existing library "family". But, the solar radiation analysis from Insight 360 did not recognize the shaded area of the ground-floor panels on the southern façade of the C3-UNAM.
3) For the third simulation test, the PVs were modeled as ceilings (Revit object) rather than a "family". Hence, the Insight 360 Plug-in recognized the shading area casted and the decrease of accumulated insolation on the ground-floor panels. It is assumed that the solar radiation tool from the Plug-in does not work if a "family" or component is inserted into the file (i.e., the "family" on the second simulation test). This is because the software took the origin (X, Y, Z) attached to the "family" file rather than the coordinates of the analyzed PVs of the C3-UNAM.

The simulations were run in the following way. Firstly, with all the PV surfaces selected (on the rooftop and on the southern facade) (Fig. 9). Later, the simulations were run separately for both systems as seen on the next images: on the rooftop (Fig. 10) and on the southern façade (Fig. 11).

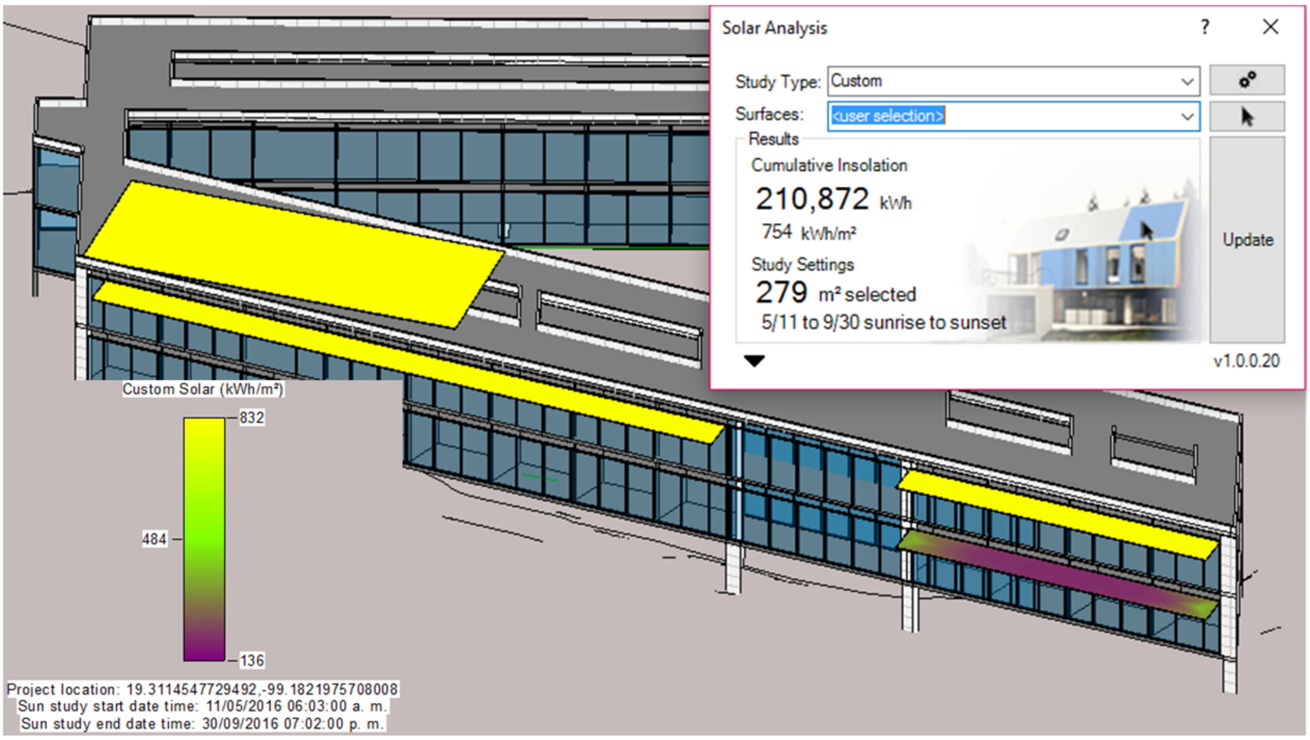

Fig. 9 Simulation of the PV System on the Rooftop and on the Southern Façade. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

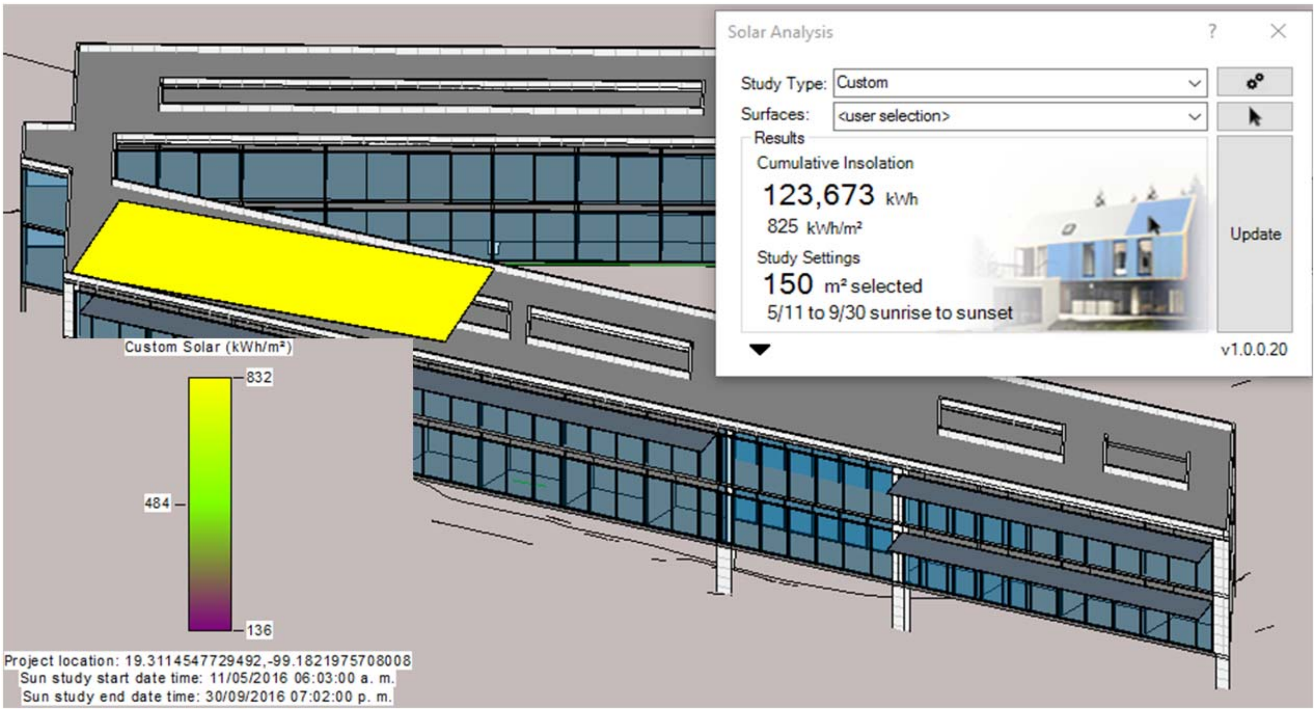

Fig. 10 Simulation of the Rooftop PV System. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

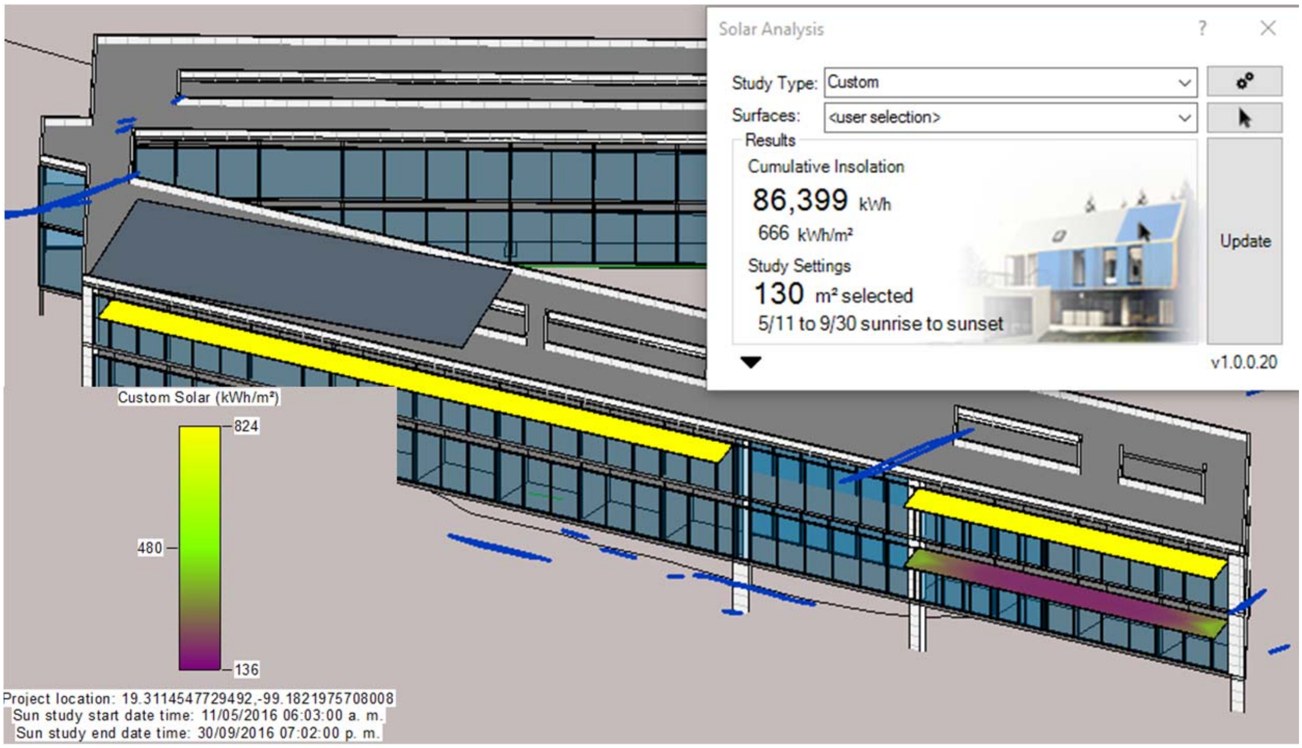

Fig. 11 Simulation of the Whole PV System on the Southern Façade. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

Then, simulations were run separately for the two different rows of the PV system on the southern façade: the ground floor PV panels (Fig. 12) and the first floor PV panels (Fig. 13).

Finally, the first floor PV panels array on the southern façade system was split in two sections and simulations were run for each one of them the western section PV panels (Fig. 14) and the eastern section PV panels (Fig. 15). The results of all the simulations were presented and compared in Table IV after Fig. 15.

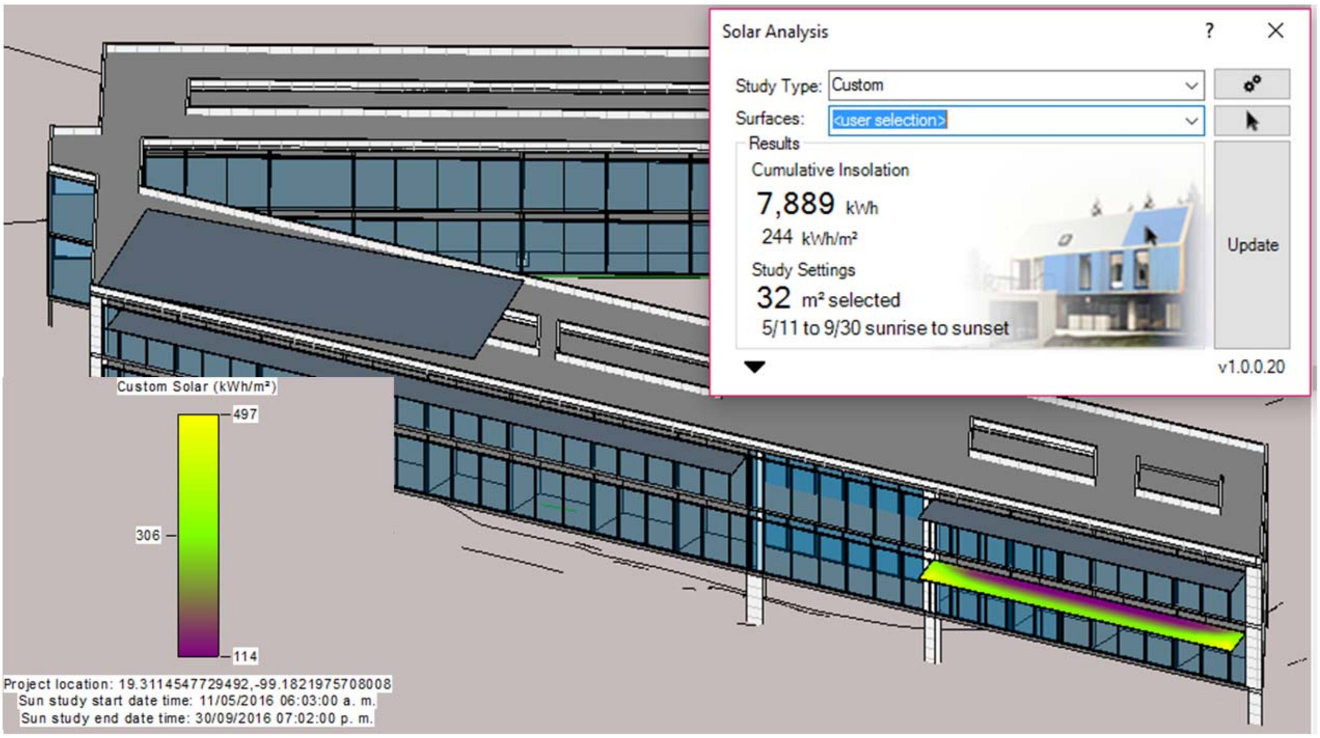

Fig. 12 Simulation of the Ground Floor Panels of the PV System on the Southern Façade. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

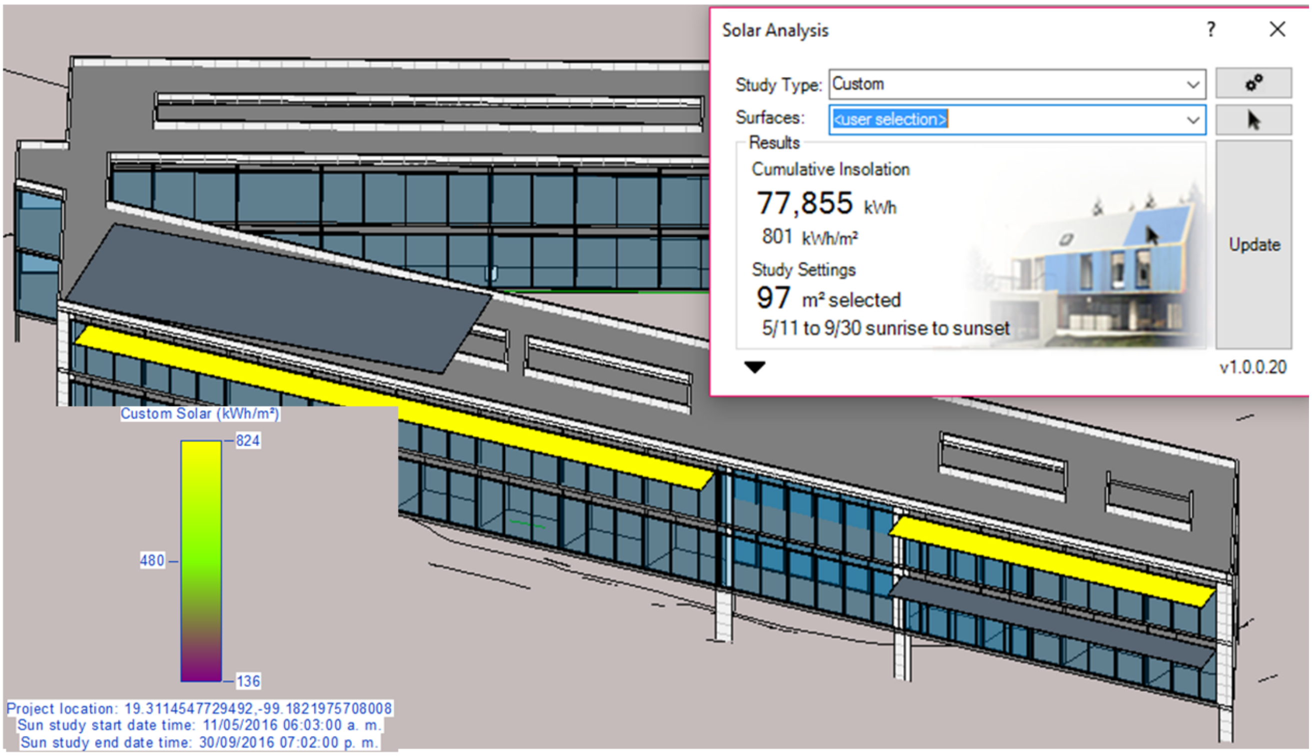

Fig. 13 Simulation of the First Floor Panels of the PV system on the Southern Façade. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

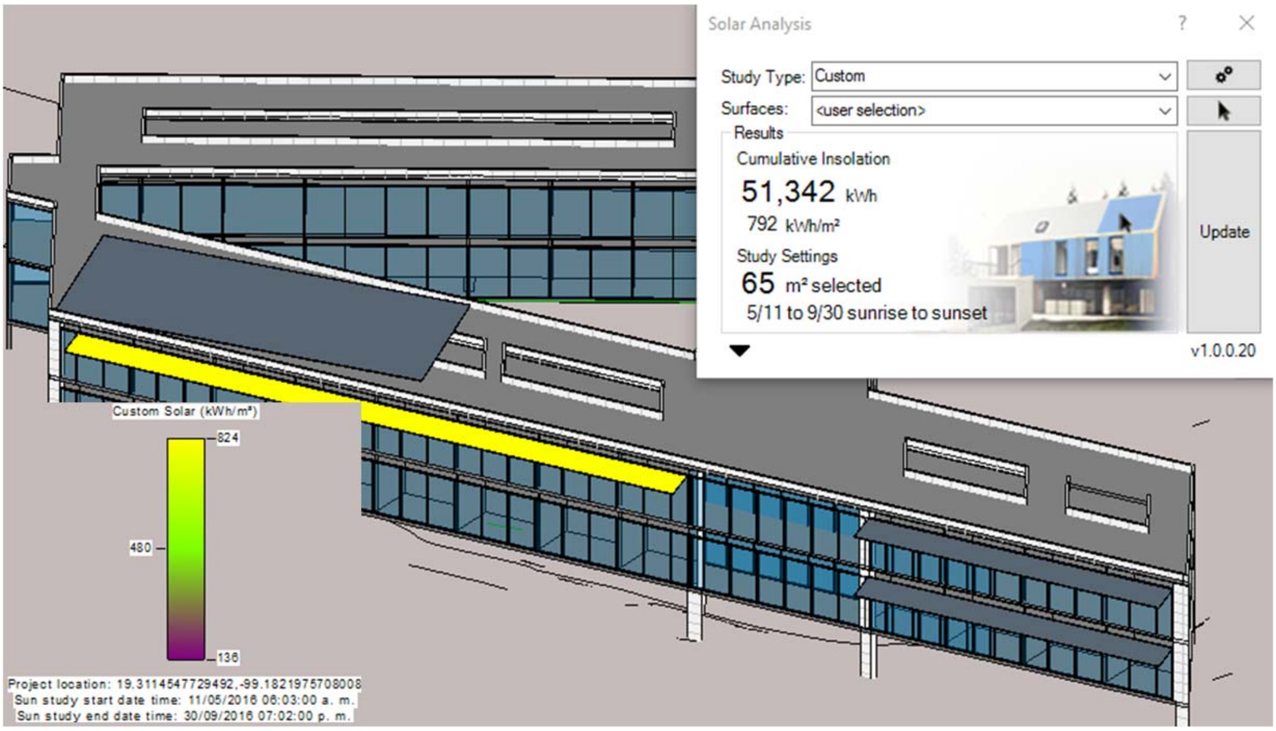

Fig. 14 Simulation of the First Floor Western Section Panels of the PV system on the Southern Façade. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

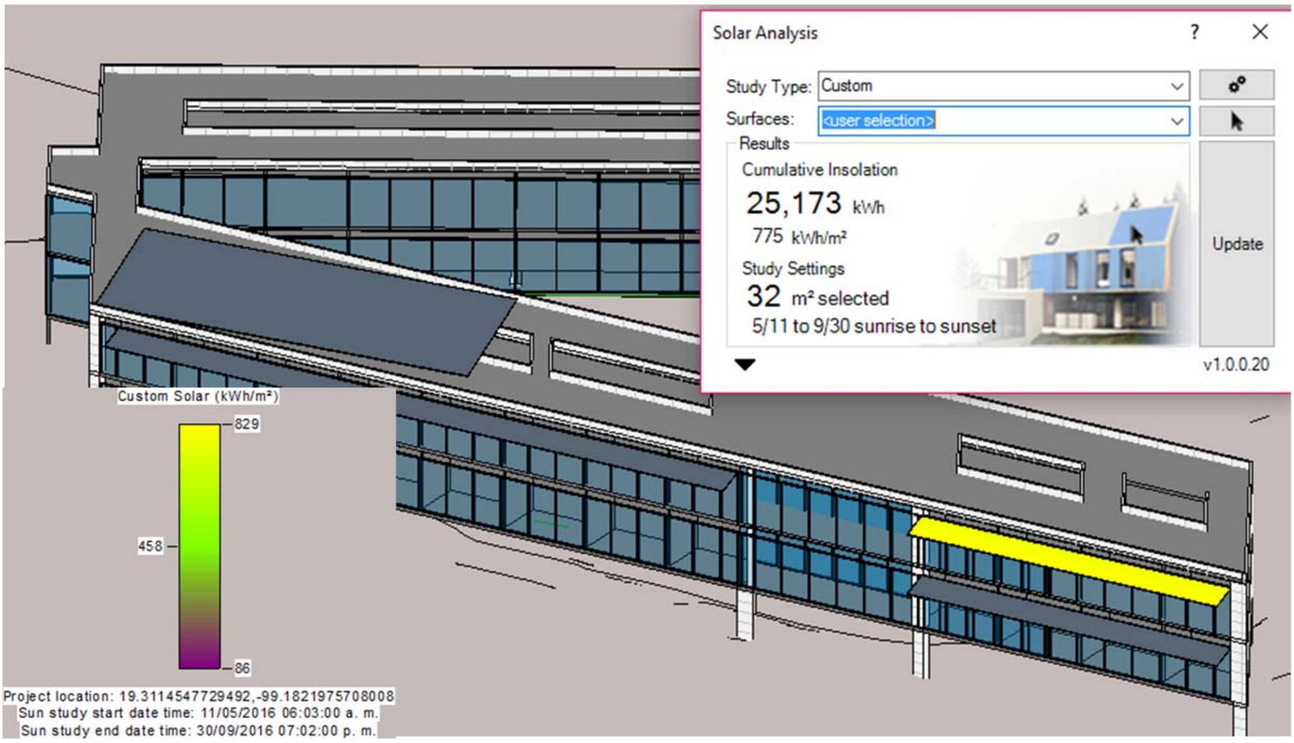

Fig. 15 Simulation of the First Floor Eastern Section Panels of the PV System on the Southern Façade. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

According to the results of the simulation, the rooftop system (Fig. 10) received the highest radiation per square meter. This is because the PV array is in optimal orientation/tilt angle conditions (South/20°). In contrast, the section of the ground floor of the façade system (Fig. 12) received the lowest insolation. This is due to the shading and the 9 degrees deviated to the west.

Due to the case study´s systems configuration, the two systems must be compared in an integral point of view: the complete PV system on the south façade (Fig. 11) plus the PV system on the rooftop (Fig. 10). It was observed that the incident irradiance per square meter decreased 159 kW/m^2 (from 825 to 666 kWh/m^2), due to the shading and slight deviation of the orientation of the PV array integrated to the south façade (Fig. 11). This corresponded to a total of 19.3% compared to the incident solar radiation on the rooftop PV system.

The results of the PV array on the ground floor southern façade (Fig. 12) and the PV array of the eastern section on the first floor southern façade (Fig. 15) showed 7,889 kWh and 25,173 kWh solar energy harvested, respectively. The loss factor by shading is clear, if these cases are compared. The PV array on the ground floor (Fig. 12) received 69% less solar energy than the PV array of the eastern section on the first floor southern façade (Fig. 15).

The losses by orientation can also be estimated by comparing the isolation per square meter (in the seventh column) falling over the rooftop system (Fig. 10) and the first floor system (Fig. 13). Both have the same tilt angle and conditions of shading and temperature, but the system of the façade is oriented with 9° deviated from the south. The insolation difference per square meter between the roof PV system and the first floor façade PV system is 24 kWh/m^2. These 24 kWh/m^2 difference represents a reduction of 2.9% in insolation due to the orientation.

TABLE IV
CUMULATIVE INSOLATION OVER THE PV SYSTEMS OF THE C3-UNAM BUILDING. RESULTS OF SOLAR RADIATION ANALYSIS SIMULATIONS USING THE INSIGHT 360 REVIT® 2018 PLUG-IN. MEASURED PERIOD: MAY 11, 2016 TO SEPTEMBER 30, 2016

Figure	System or section	Number of panels (unit)	Surface (m^2)[9]	Surface percentage (%)	Cumulative insolation (kWh)	Insolation per m^2 (kWh/m^2)
9	Rooftop + South Façade	172	279	100%	210,872	754
10	Rooftop	92	150	53.76%	123,673	825
11	Whole South Façade	80	130	46.59%	86,399	666
12	South Façade-Ground Floor	20	32	11.47%	7,889	244
13	South Façade-First Floor	60	97	34.77%	77,855	801
14	Western Section of South Façade-First Floor	40	65	23.3%	51,342	792
15	Eastern Section of South Façade-First Floor	20	32	11.47%	25,173	775

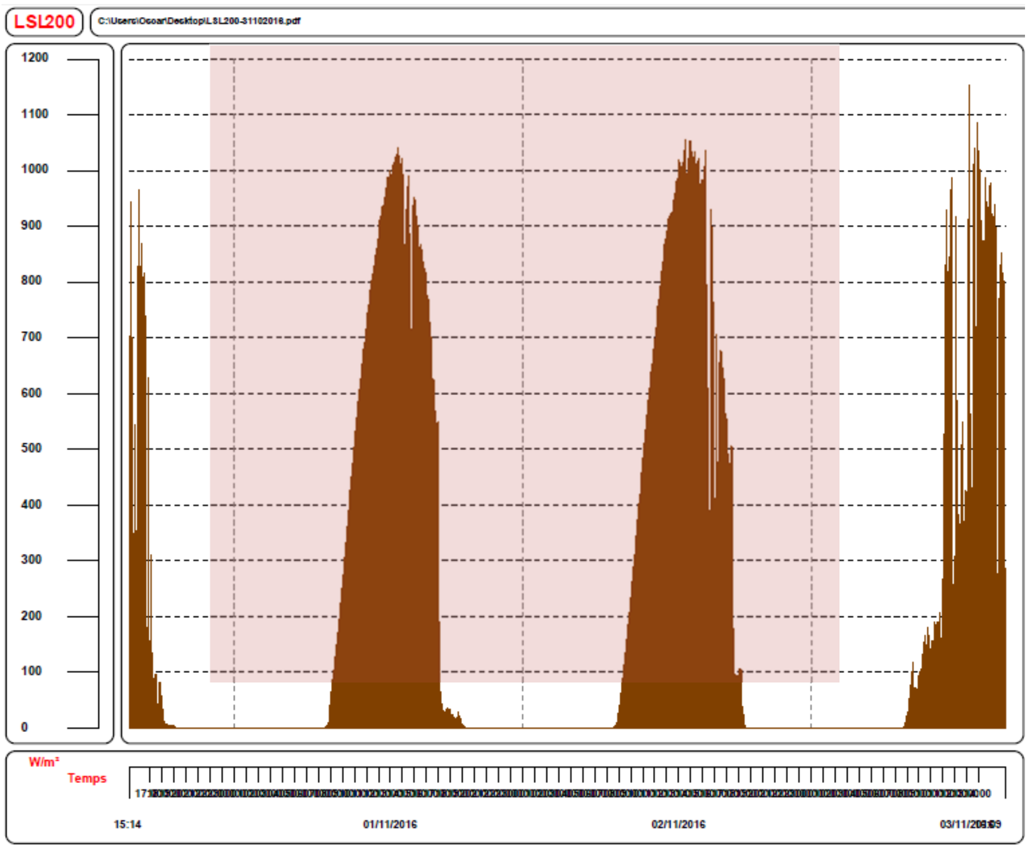

Fig. 16 Global Cumulative Insolation (from 3:14 p. m. on October 31st, 2016 to 4:09 p. m. on November 3rd, 2016)

[i j k] The data arew2 presented exactly as shown in the results window of the solar analysis from the Insight 360 Plug-in of Revit 2018® simulations.

B. Validation of Simulation Results

The data obtained from the simulation analysis of the rooftop PV system of the C3-UNAM was validated by comparing its results to the measured data from the experiment performed on the rooftop of the Postgraduate Building. The experiment was done on the rooftop of the "J" Block Section of the Postgraduate Building, due to the lack of surrounding tall buildings that may block solar access on its rooftop.

Table V shows the mean, maximum value and the cumulative insolation of the measured data results for November 1st and November 2nd, 2016. Fig. 16 presents the records of the whole measurement from October 31st to November 3rd, 2016. The horizontal axis represents the time period (min) and the vertical axis represents the irradiance (W/m^2). It was only considered the data measured from November 1st to November 2nd,2016. The final result was 12.46 kWh/m^2 for cumulative insolation. This was compared to the computer simulation's final result.

TABLE V
STATISTICS OF THE EXPERIMENT FROM THE UNAM´S GRADUATE UNIT FROM NOVEMBER 1ST TO NOVEMBER 2ND, 2016

Parameter	Value
Max value	1,055 W/m^2
Mean	543.88 W/m^2
Cumulative Insolation	12.46 kWh/m^2

The computer simulations for the same analyzed period indicated a cumulative insolation of 11.27 kWh/m^2. The difference between this simulation final result and the on-site measured data is of 1.19 kWh. This difference represented less than 10% between both results (Fig. 17).

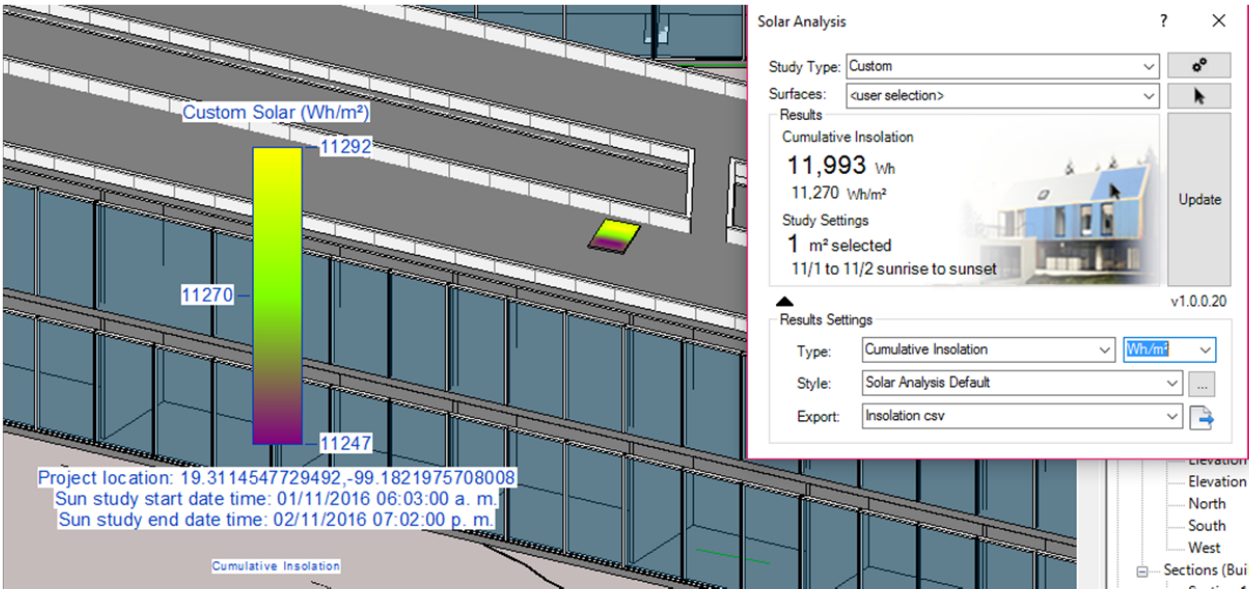

Fig. 17 Simulation of Incident Solar Radiation on a Surface of 1 square meter in the period for November 1st and 2nd, 2016. Image created using the Insight 360 Plug-in of Revit 2018® by Viridiana Ardura Perea

V. CONCLUSIONS

This study has led the authors to conclude that the use of computer simulations tools, such as Insight 360 Plug-in of Revit 2018®, allows to obtain results close to the real world. It can be inferred that the loss factor that most impacted the PV systems´ electricity generation on the façade of the C3-UNAM is the shading. It is worthy to point out that the systems´ conditions on the rooftop and the south facade are practically the same. The only differences are the orientation and the shading.

A decrease of 68.5% in cumulative insolation per square meter (kWh/m^2) was observed over the eastern panels on the ground floor when compared to the performance of the eastern panels on the first floor. This indicates that if environmental conditions are not considered on early design stages of a PV array (i.e. potential shading from other elements), the reduction on incident insolation can affect the overall performance of a PV system with losses greater than 50%.

On the case study, the shading of the PV system on the ground floor on the south façade impacts the average insolation per square meter of the entire system placed on the façade and obtained a 19.3% decrease. If this percentage is added to the 2.9% loss from the orientation analysis case Science Center of Complexity, 22.2% is the total loss percentage of the PV system on the façade compared to the PV system on the rooftop. On the other hand, it was observed that the PV system located on the south façade of the C3-UNAM, according to the on-site measured data provided by the facility manager, generated 42% less electrical energy per kWp installed than the PV system on the rooftop. The difference of percentage losses between the on-site measured data and the simulation results is 20%. Finally, if the validated computer simulation results in this study are compared to the empirical evidence experiment results, the difference on the global insolation measurement is 9.5%.

It is suggested to analyze the following elements for future studies: 1) the effects of shading that can cause mismatch on the current, 2) the voltage generated by the arrangement and 3) the effect of temperature on electricity generation. These are factors that might also influence the power generation reduction.

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REFERENCES

[1] European Renewable Energy Council, 2010. European Renewable Energy Council (2010). *RE-thinking 2050-a 100% renewable energy vision for the European Union*. Accessed 2017-09-17 from http://www.erec.org/.

[2] Instituto Nacional de Ecología y Cambio Climático INECC. (2013). *Inventario de Gases y Compuestos de Efecto Invernadero 2013.* (Digital Version) Accessed 2016-09-05 from: //www.inecc.gob.mx /descargas/cclimatico/2015_inv_nal_ emis_gei_result.pdf.

[3] Secretaría de Energía (SENER). (2014) *Balance Nacional de Energía*. (Digital Version]. Accessed 2016-11-05 from https://www.gob.mx/cms/uploads/attachment/file /44353/Balance_Nacional_de_ Energía_2014.pdf.

[4] Secretaría de Energía (SENER). (2016) *Inventario Nacional de Energías Renovables (INERE) (SIE).* Accessed 2016-09-15 from: http://inere.energia.gob.mx/version4.5/.

[5] Jaramillo, O.A., Martínez, M., Tenorio, J.A. y del Río, J.A. (2015). *Estrategia de Transición para promover el uso de Tecnologías y Combustibles más limpios en el tema de energía solar*: Instituto Nacional de Energías Renovables, Ciudad de México, México: Universidad Nacional Autónoma de México.

[6] Programa de Maestría y Doctorado en Arquitectura (2016). *Diagnóstico del Centro de Ciencias de la Complejidad C3.* Ciudad de México, México: Universidad Nacional Autónoma de México.

[7] Gómez, M (2016). *Datos de sistemas fotovoltaicos del edificio del Centro de Ciencias de la Complejidad C3*. Ciudad de México, México: Universidad Nacional Autónoma de México.

[8] Martín, N. y Fernández, I. (2007*) La envolvente FOTOVOLTAICA en la Arquitectura.* Barcelona, España: Editorial Reverté.

[9] Meinel, A.B. y Meinel, M.P. (1982). *Aplicaciones de la energía solar*. España: Editorial Reverté.

[10] Hersch, P., Zweibel, K. and Solar Energy Research Institute (1982). *Basic Photovoltaic Principles and Methods Volume 6213 of Solar information module*, United States: Technical Information Office, Solar Energy Research Institute.

[11] Daniels, K. (1997). *Technology of ecological building.* Birkhauser Boston.

[12] Alonso-Abella M, Chenlo F. *A model for energy production estimation of PV grid connected systems based on energetic losses and experimental data. In: On site diagnosis,* European Photovoltaic Solar Energy Conference; 2004. p. 2447–50.

[13] Solartec (2016). S36MC Technical Data Sheet. Accessed 2016-11-05 from: http: //www.solartec.mx/upload/S60PC.pdf.

[14] Kimo Instruments (2018). SL 200 Solarimeter Technical Data Sheet. Accessed 2018-03-15 from: http://kimo-instruments.com/sites/kimo.fr/files/2017-09/FTang_SL200_19-02-15.pdf.

[10] Original in Spanish: Programa de Apoyo para Estudiantes de Posgrado (PAEP).