DOCKETED	
Docket Number:	22-BSTD-02
Project Title:	2022 Energy Code Compliance Software & Supporting Documents
TN #:	246467
Document Title:	2022 ACM Appendix C - Photovoltaics
Description:	Updated version of the 2022 Alternative Calculation Method Reference Manual Appendix C - Photovoltaics.
Filer:	Haile Bucaneg
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	10/11/2022 1:58:20 PM
Docketed Date:	10/11/2022

APPENDIX C: PHOTOVOLTAICS

Photovoltaics

The compliance software calculates energy generated by photovoltaic (PV) systems on an hourly basis using the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) algorithms upon which the PVWatts program is based (see Appendix F). PV systems with and without sub-array power electronics (i.e., microinverters and DC power optimizers) are further considered based on user inputs.

Power electronics are used to help minimize efficiency losses when the output of sub-array components (e.g., modules or cells) operate under different conditions. The largest driver of variation in conditions across a PV array is partial shading from nearby obstacles. A small fraction of shaded cells could lead to disproportionate reductions in PV power output. PVWatts, does not explicitly handle this effect. Literature describes a shading impact factor (SIF) which is the ratio of relative power output to fraction shaded:

$$P_{sh} = P_{sys} \cdot (1\text{-}SIF \cdot f_{sh})$$

Where P_{sh} is the power output of the shaded system, P_{sys} is the power output of the unshaded system, and f_{sh} is the fraction shaded.

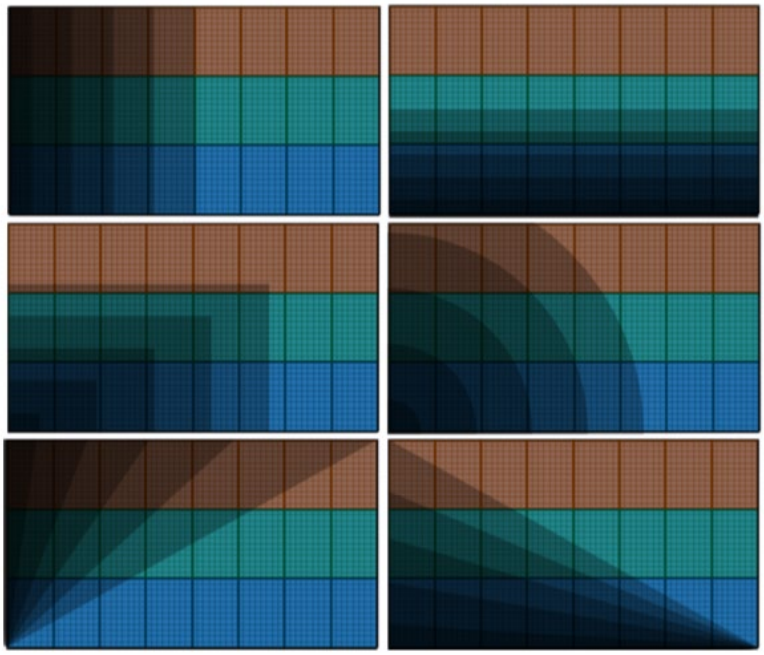
A value of 1.0 implies that the power output declines proportionally to the fraction shaded. This is a theoretical minimum value of SIF in that it implies there are power electronics that are maintaining output consistent with the level of shading across the module. A value greater than 1.0 implies that shading has a disproportionate effect on system output.

How the individual cells within an array are shaded can have a significant impact on SIF. This is illustrated in a study on a PV module without power electronics (see Figure C-1).

In this study the same module was shaded in different fashions (see Figure C-2). For a given shade ratio, the actual output from the PV system can differ by 30 percent depending on which portions of the system are shaded (Note: the dotted lines in the first figure represent SIF values of 1.0 [y = 1 – 1.0*x] and 2.0 [y = 1 – 2.0*x] and serve as approximate bounds on the impact). Without cell-level fidelity in our shading model, it is impossible to know which specific cells are shaded at any given time. The compliance software will use a coarse approximation of SIF appropriate for panel and/or array level analysis.

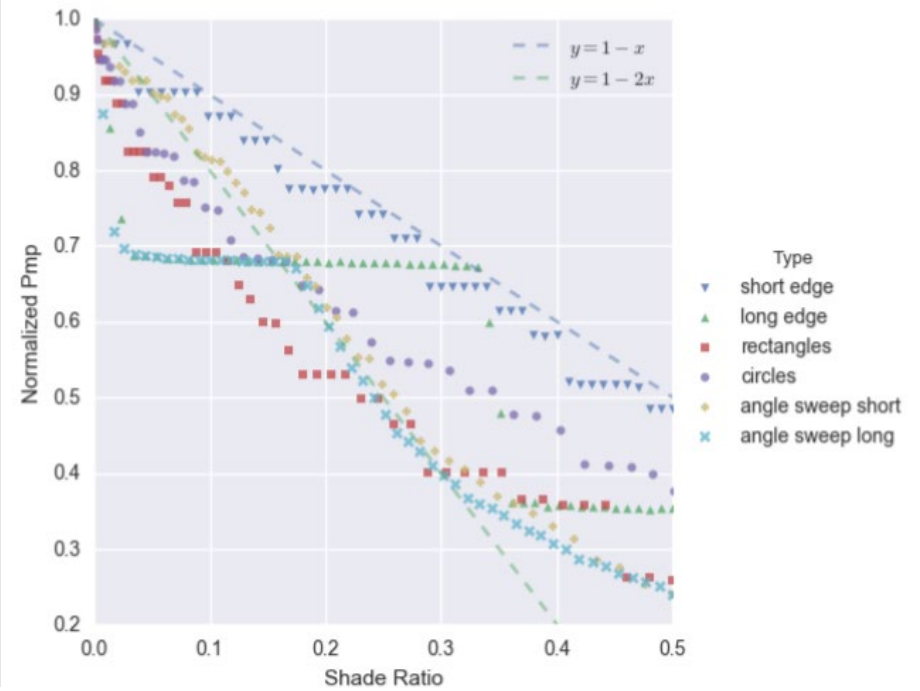
SIF should also change with higher levels of irradiance as shown in this study (see Table C-2). However, considering the coarseness of array-wide shading fraction (vs. cell-by-cell), accounting for this effect is not likely to provide a substantial increase in overall accuracy.

FIGURE C-1



Source: California Energy Commission

FIGURE C-2



Source: California Energy Commission

One problem with applying shading impact factors directly to the power output of the system is that there is a theoretical lower limit to PV production under shaded conditions: diffuse irradiance. Unless a cell is also blocked from diffuse solar (e.g., the shade is very close to the panel and blocking cells from the rest of the sky), all cells will receive a minimum level of incidence. To account for this, we propose introducing an alternative formulation using an "effective" plane-of-array incidence, where only the beam component is affected by shading.

$I_{poa,eff} = I_{poa,diff} + I_{poa,beam,eff}$

$I_{poa,beam,eff} = \max(I_{poa,beam}*(1-SIF*f_{sh}), 0.0)$

The compliance software shall use an SIF value of 2.0 for central inverters (CEC default) and a value of 1.2 for systems with power electronics (based on a 40 percent shade loss recovery as defined in this paper--see Table C-2. SIF for Total Inverter Efficiency).

System Loss Assumptions

In PVWatts, a single derating factor is used to cover a variety of system inefficiencies. The compliance software uses slightly different assumptions for this derating factor as described in the table below:

TABLE C-1. DERATING FACTOR

Loss Type	Value	Differences from PVWatts Default Assumptions
Soiling	0.02	N/A
Shading	0.0	Modeled explicitly
Snow	0.0	N/A
Mismatch	0.0	Mismatch from shading is characterized using SIF
Wiring	0.02	N/A
Connections	0.005	N/A
Light-induced degradation	0.015	N/A
Nameplate rating	0.01	N/A
Age	0.05	Estimated 0.5 percent degradation over 20 years based on these references: [1, 2, 3]
Availability	0.03	N/A
Total	0.14	N/A

Source: California Energy Commission

Inverter Efficiency

The software shall characterize the inverter efficiency corresponding to either a central inverter or microinverters depending on the type of power electronics used in the system.

Power Electronics

Options for power electronics are described below:

TABLE C-2. SIF FOR TOTAL INVERTER EFFICIENCY

Option	SIF	Total Inverter Efficiency
None	2.0	User input
Microinverters	1.2	User input
DC Power Optimizers	1.2	Optimizer efficiency * user input

Source: California Energy Commission

Optimizer efficiencies are assumed to be 0.99 (corresponding to suggestions in this document).

Space Function to PV/Battery Building Type Mapping

The software shall determine the size of the building PV and battery system based on the PV Capacity Factors and Battery Storage Capacity Factors. The PV Capacity Factors identify the capacity of a PV system based on the climate zone, building type, and conditioned floor area. The Battery Storage Capacity Factors identify the Energy Capacity or Power Capacity based on the building type and PV capacity. The mapping of space function to PV capacity factor building type is documented in the following table.

TABLE C-3. SPACE FUNCTION TO PV/BATTERY BUILDING TYPE MAPPING

Space Function	PV/Battery Building Type
Aging Eye/Low-vision (Corridor Area)	Other*
Aging Eye/Low-vision (Dining)	Other*
Aging Eye/Low-vision (Lobby, Main Entry)	Other*
Aging Eye/Low-vision (Lounge/Waiting Area)	Other*
Aging Eye/Low-vision (Multipurpose Room)	Other*
Aging Eye/Low-vision (Religious Worship Area)	Other*
Aging Eye/Low-vision (Restroom)	Other*

Aging Eye/Low-vision (Stairwell)	Other*
Audience Seating Area	Other*
Auditorium Area	Other*
Auto Repair / Maintenance Area	Retail
Barber, Beauty Salon, Spa Area	Retail
Civic Meeting Place Area	Other*
Classroom, Lecture, Training, Vocational Areas	School
Computer Room	Office, Financial Institutions, Unleased Tenant Space
Concourse and Atria Area	Other*
Convention, Conference, Multipurpose and Meeting Area	Other*
Copy Room	Office, Financial Institutions, Unleased Tenant Space
Corridor Area	Other*
Dining Area (Bar/Lounge and Fine Dining)	Other*
Dining Area (Cafeteria/Fast Food)	Other*
Dining Area (Family and Leisure)	Other*
Electrical, Mechanical, Telephone Rooms	Office, Financial Institutions, Unleased Tenant Space
Exercise/Fitness Center and Gymnasium Areas	Retail
Financial Transaction Area	Office, Financial Institutions, Unleased Tenant Space
Healthcare Facility and Hospitals (Exam/Treatment Room)	Other*
Healthcare Facility and Hospitals (Imaging Room)	Other*
Healthcare Facility and Hospitals (Medical Supply Room)	Other*
Healthcare Facility and Hospitals (Nursery)	Other*
Healthcare Facility and Hospitals (Nurse's Station)	(no requirement)
Healthcare Facility and Hospitals (Operating Room)	(no requirement)
Healthcare Facility and Hospitals (Patient Room)	(no requirement)
Healthcare Facility and Hospitals (Physical Therapy Room)	Other*

Healthcare Facility and Hospitals (Recovery Room)	(no requirement)
High-Rise Residential Living Spaces	High-Rise Multifamily
Hotel Function Area	Other*
Hotel/Motel Guest Room	Other*
Kitchen/Food Preparation Area	Other*
Kitchenette or Residential Kitchen	Other*
Laboratory, Scientific	(no requirement)
Laundry Area	High-Rise Multifamily
Library (Reading Area)	Other*
Library (Stacks Area)	Other*
Lobby, Main Entry	Other*
Locker Room	Other*
Lounge, Breakroom, or Waiting Area	Other*
Manufacturing, Commercial & Industrial Work Area (Low Bay)	(no requirement)
Manufacturing, Commercial & Industrial Work Area (High Bay)	(no requirement)
Manufacturing, Commercial & Industrial Work Area (Precision)	(no requirement)
Museum Area (Exhibition/Display)	(no requirement)
Museum Area (Restoration Room)	(no requirement)
Office Area (>250 square feet)	Office, Financial Institutions, Unleased Tenant Space
Office Area (<250 square feet)	Office, Financial Institutions, Unleased Tenant Space
Parking Garage Area (Parking Zone and Ramps)	(no requirement)
Parking Garage Area (Daylight Adaptation Zones)	(no requirement)
Pharmacy Area	Retail
Retail Sales Area (Grocery Sales)	Grocery
Retail Sales Area (Retail Merchandise Sales)	Retail

Retail Sales Area (Fitting Room)	Retail
Religious Worship Area	Other*
Restrooms	Other*
Stairwell	Other*
Storage, Commercial/Industrial (Warehouse)	Warehouse
Storage, Commercial/Industrial (Refrigerated)	Warehouse
Storage, Commercial/Industrial (Shipping & Handling)	Warehouse
Sports Arena - Playing Area (> 5,000 Spectators)	Other*
Sports Arena - Playing Area (2,000 - 5,000 Spectators)	Other*
Sports Arena - Playing Area (< 2,000 Spectators)	Other*
Sports Arena - Playing Area (Recreational)	Other*
Theater Area (Motion Picture)	Other*
Theater Area (Performance)	Other*
Transportation Function (Baggage Area)	(no requirement)
Transportation Function (Ticketing Area)	(no requirement)
Unleased Tenant Area	Office, Financial Institutions, Unleased Tenant Space
Unoccupied-Exclude from Gross Floor Area	(no requirement)
Unoccupied-Include in Gross Floor Area	Other*
Videoconferencing Studio	Office, Financial Institutions, Unleased Tenant Space
All other	(no requirement)

*Other PV/Battery building type includes: Auditorium, Convention Center, Hotel/Motel, Library, Medical Office Building/Clinic, Restaurant, Theater

Source: California Energy Commission

Battery Storage

See Status of Modeling Batteries for California Residential Code Compliance, Appendix D.