Where Renewable Energy Meets the Building Envelope – The Building Science Aspects of Photovoltaic Integration With Roof Systems

NRCA Technical Symposium
Washington, DC

James D Katsaros, PhD
DuPont Building Innovations
September 9, 2011

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Outline

- Some Thoughts on the Building Envelope & Penetrations
- A Case for Standardization of Roof Mounted PV Systems
- Some work going on at ASTM E44
- Preliminary Data on the Thermal Impact of BIPV Roof Configurations

"Beware of the unexpected consequences from using emerging roof technologies…"

Mark Graham, 9/7/2011

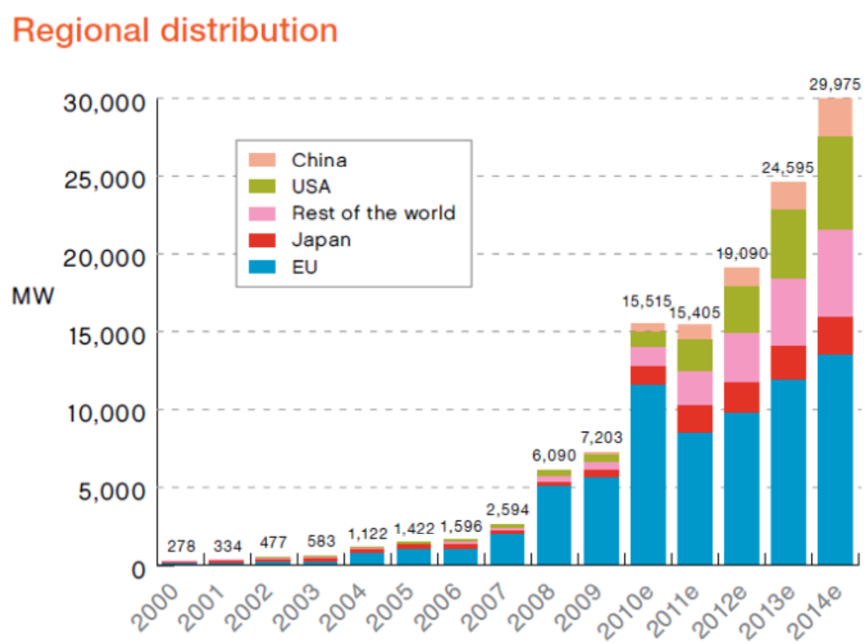


Figure 5 - Regional PV distribution in the World (Policy-Driven scenario)

The Building Envelope:

The continuous separation between conditioned or semi-conditioned space (interior) with unconditioned space (exterior)

Manages the air / water / thermal interface between the interior living space and the exterior

Building Envelope Discontinuities (i.e., windows / doors / other penetrations) pose special challenges to maintaining the Building Envelope performance

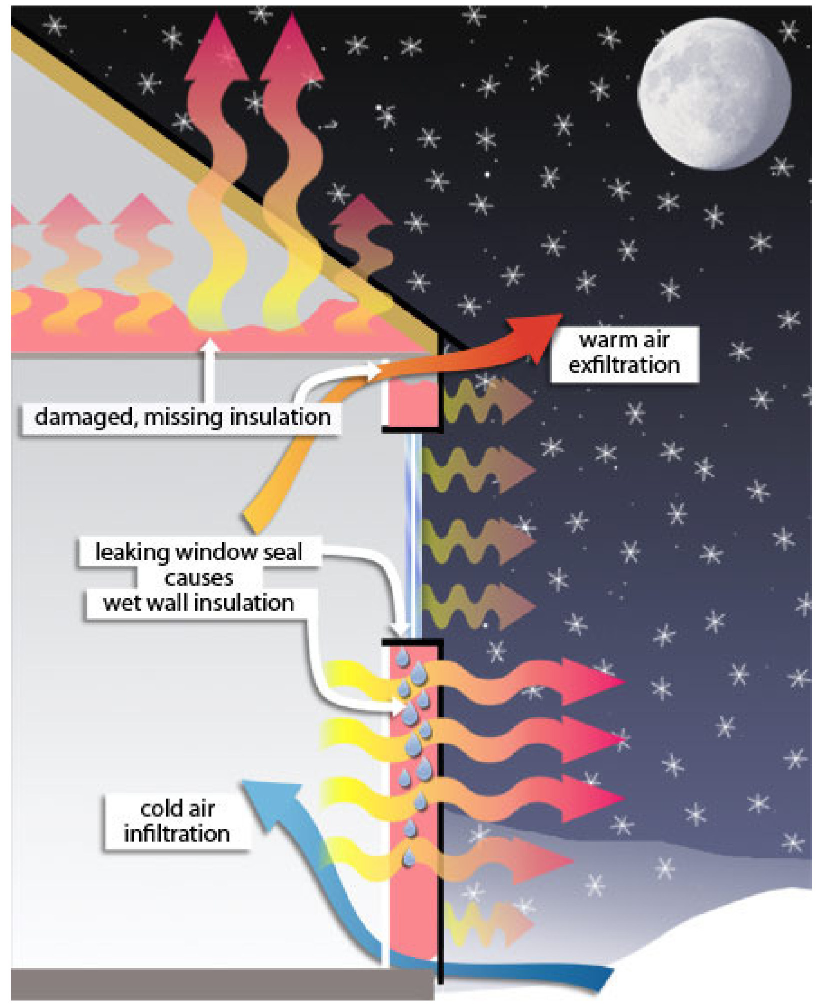
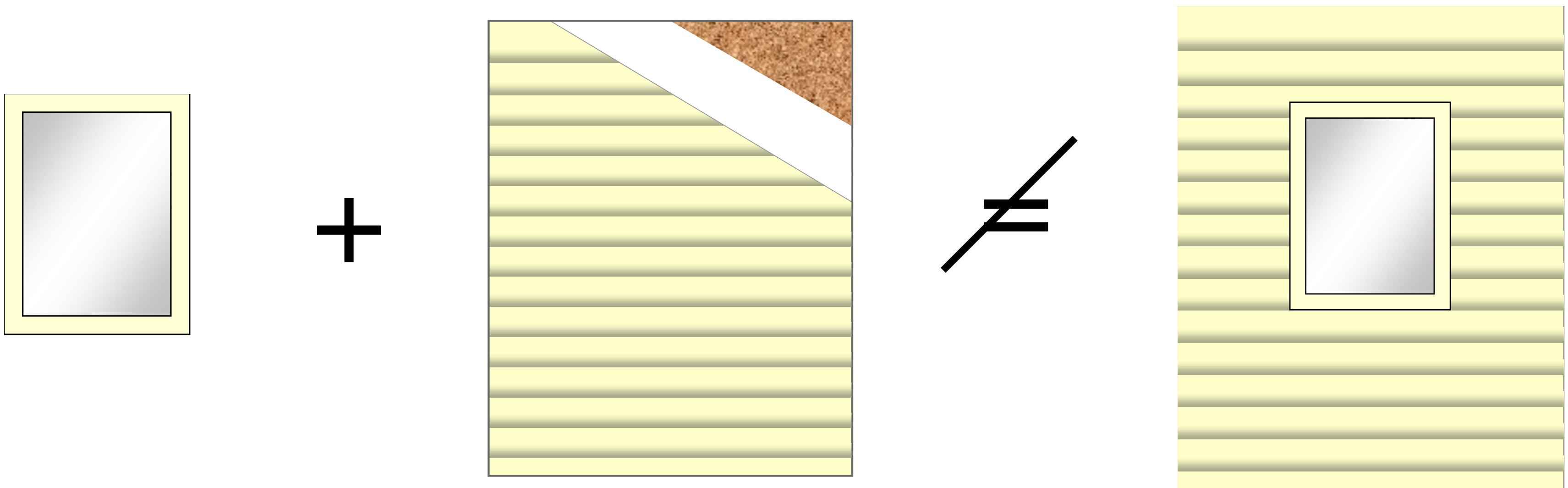


Image from: http://www.iranalyzers.com/home/

Building Envelope Discontinuities: Windows and Walls



Significant effort has focused on the development of installation methods that are standardized and tested at the window / wall interface as an installed system.

Window & Door Installation Standards

Building Envelope Discontinuities:
What about when Renewable Energy meets the Roof?

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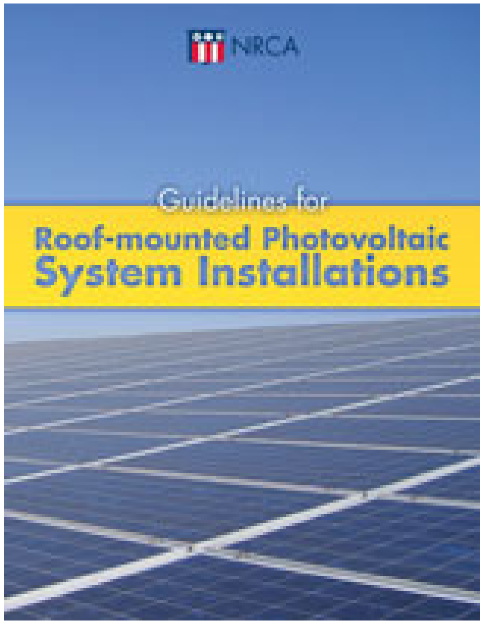
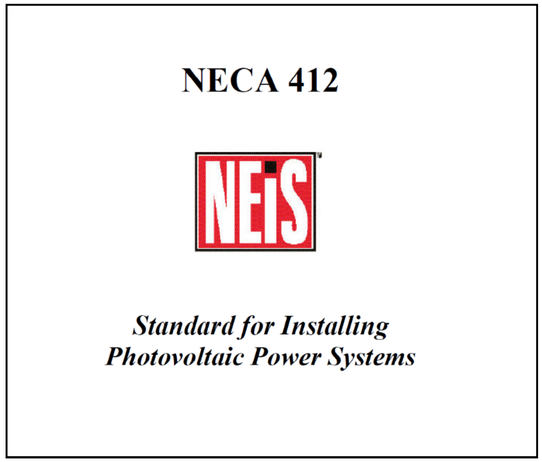
Key Issues :

- Roof performance & durability
- Attic performance & durability
- PV performance & durability
- Interactions & Tradeoffs: How each is impacted by the other

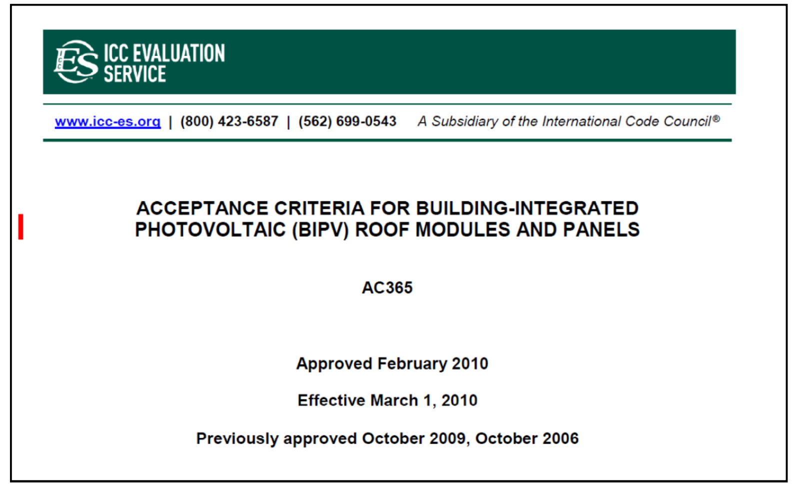
Roof Mounted PV Installation Standards




NECA 412

NEIS

Standard for Installing Photovoltaic Power Systems


ICC EVALUATION SERVICE

www.icc-es.org | (800) 423-6587 | (562) 699-0543 *A Subsidiary of the International Code Council®*

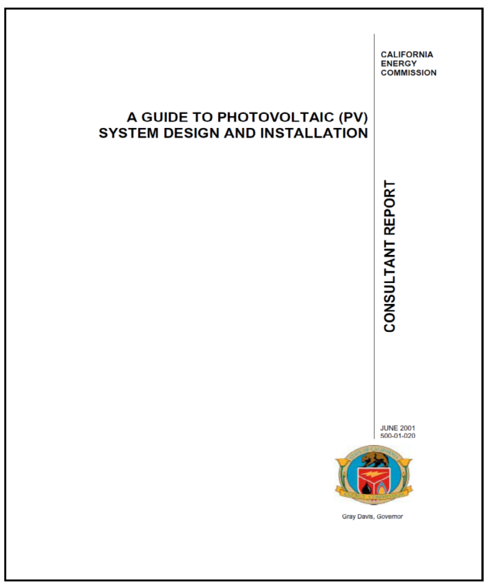
ACCEPTANCE CRITERIA FOR BUILDING-INTEGRATED PHOTOVOLTAIC (BIPV) ROOF MODULES AND PANELS

AC365

Approved February 2010

Effective March 1, 2010

Previously approved October 2009, October 2006


CALIFORNIA ENERGY COMMISSION

A GUIDE TO PHOTOVOLTAIC (PV) SYSTEM DESIGN AND INSTALLATION

CONSULTANT REPORT

JUNE 2001
500-01-020

Gray Davis, Governor

Excellent (essential) general guidance on design / connectivity / practical installation considerations

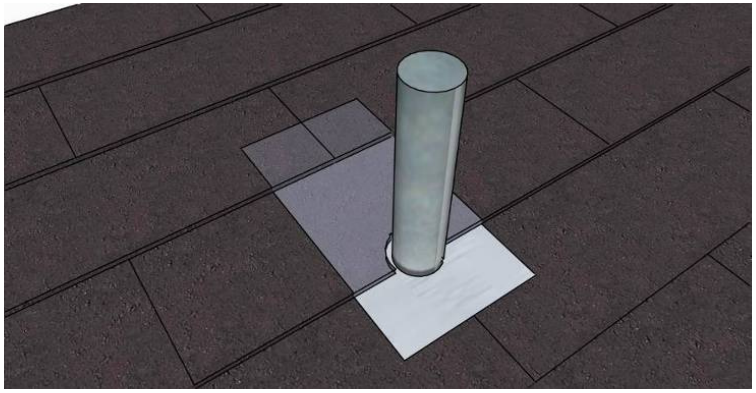
Still need specifics on…

- Regional Structural Load Requirements
- Analysis of the key Interfaces (module / array & array / roof)
- Durability of Array Mounting System (racking materials, adhesives, …)
- Verifiable Performance Requirements for Roof Integration

ASTM E44.09 - WK21327
Standard Practice for Installation of Roof Mounted Photovoltaic Arrays on Steep-Slope Roofs

Addressing specifications for:

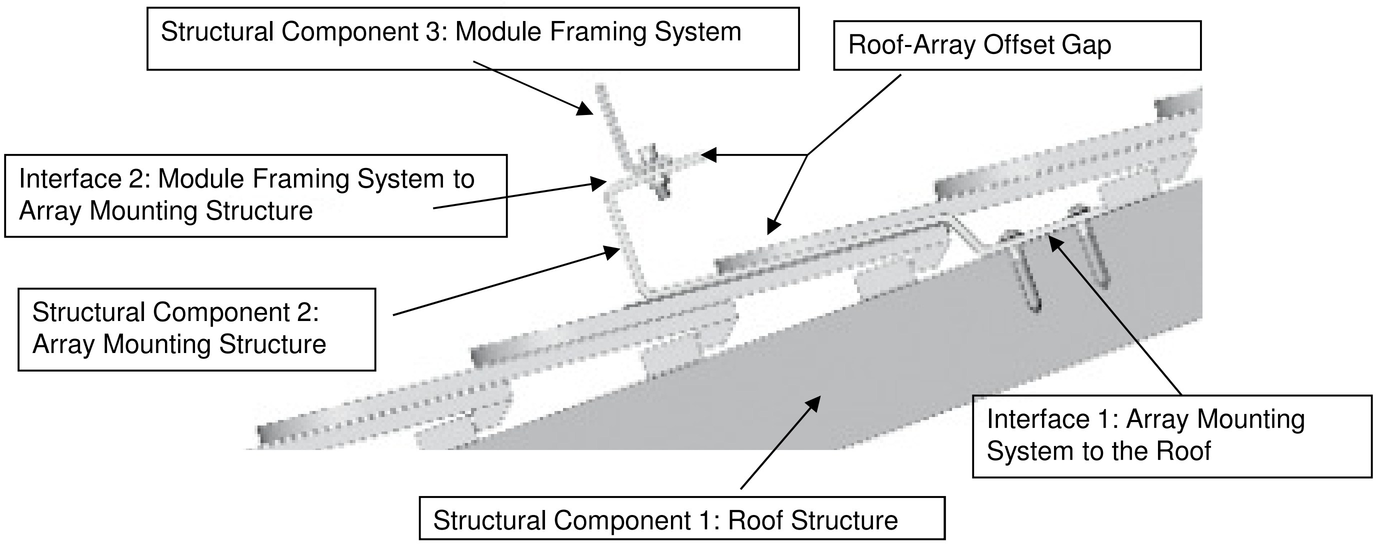
- Expected Design Life of PV System Components
- Compatibility of Design Life between PV and Roof System (don't put a 25 year PV system on a roof with a 5-10 year life)
- Material Considerations for Adhesion / Corrosion / Combustibility
- Structural Design Considerations – Live / Dead Loads
- Proper Roof Integration - Water Managed Penetrations (validated by testing)
- References to Hazard Considerations (electrical exposure / fall protection…)
- Analysis of the Key Interfaces….



Document under development…..other systems (flat roof / BIPV) to follow….

ASTM E44.09 WK21327:
Interfacial / Component Approach

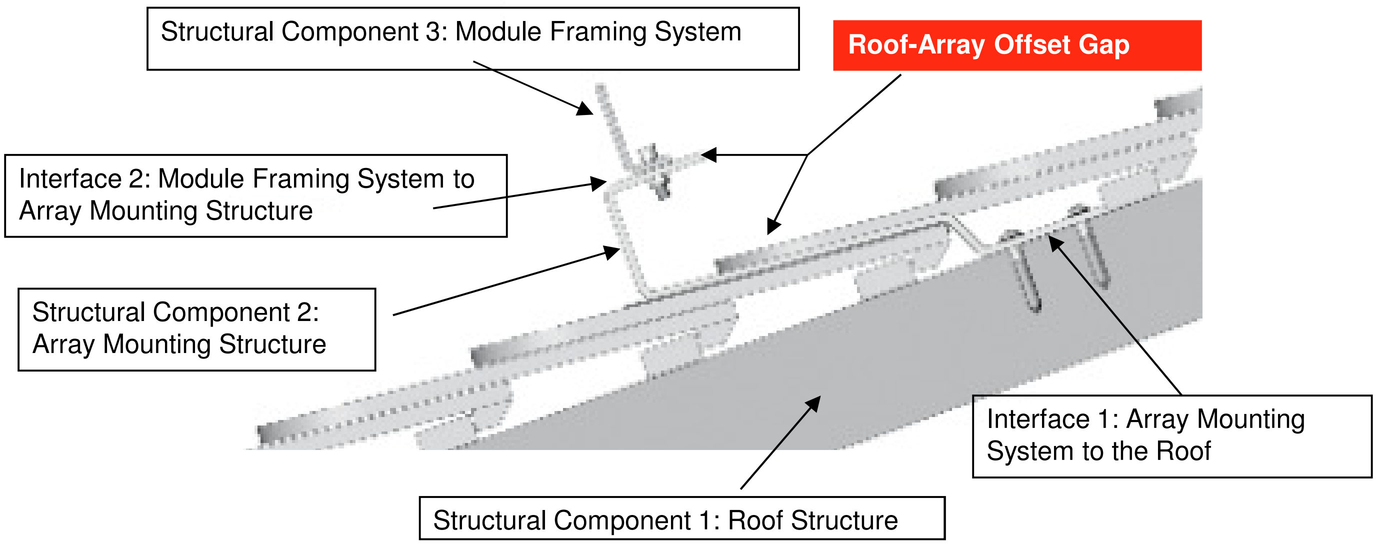
Each interface and structural component plays a distinct role in the overall performance of the installation



This standard practice defines specifications / requirements for each individual component & interface

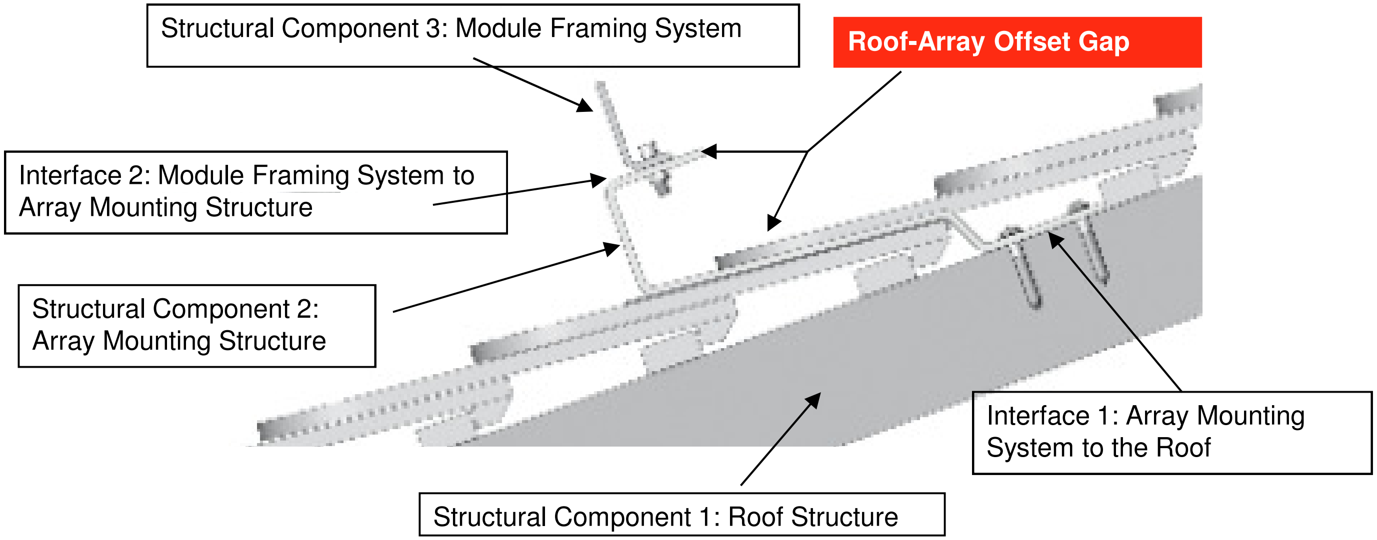
ASTM E44.09 WK21327:
Interfacial / Component Approach

Lets focus on the impact of one key feature – the Roof-Array Offset Gap….



The Building Science Impact of the Roof-Array Offset Gap

Wind Uplift	Higher RAOG will result in higher structural/wind load requirements for the array mounting system – impact needs to be better quantified



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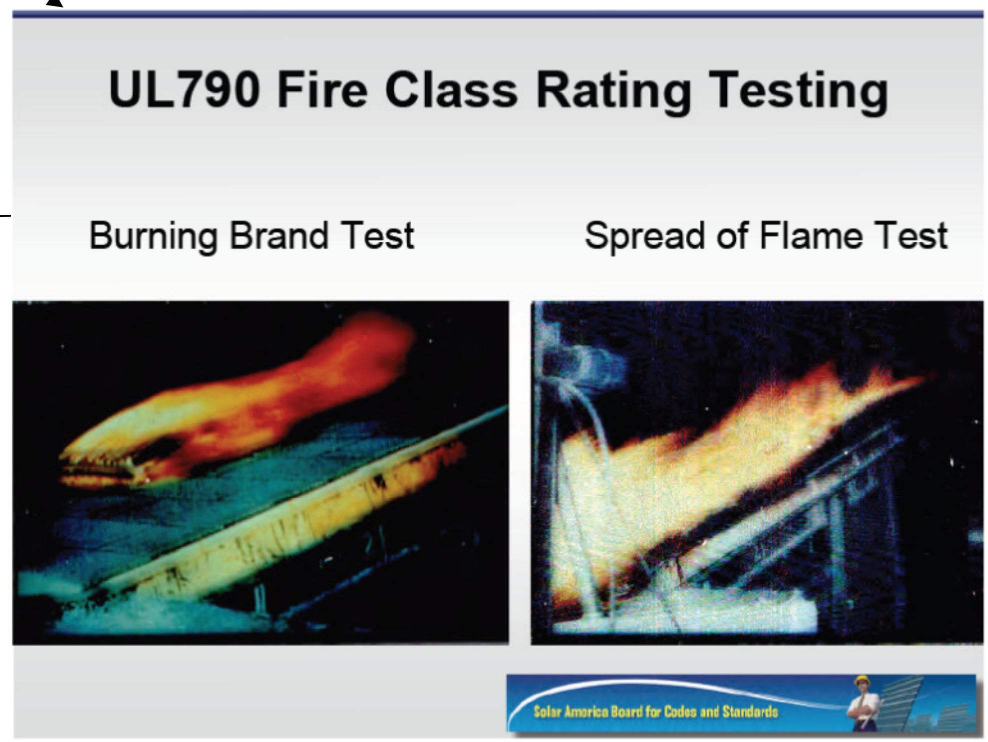
2012 IBC 1509.6.2 Fire Classification. Rooftop mounted photovoltaic systems shall have the same fire classification as the roof assembly as required by Section 1505.



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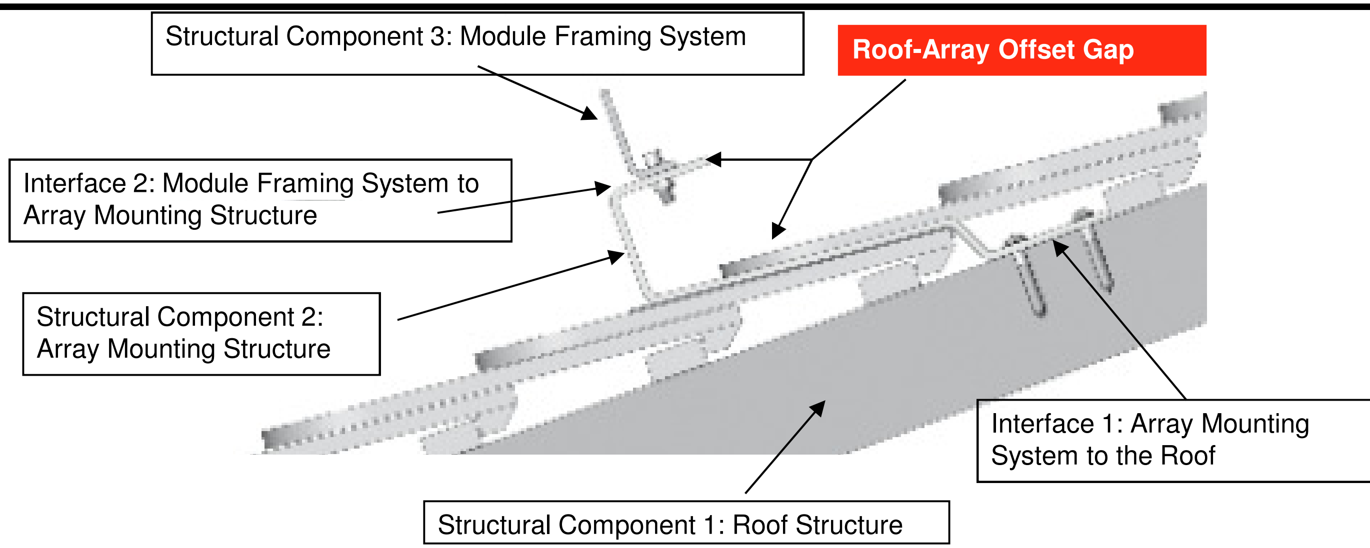
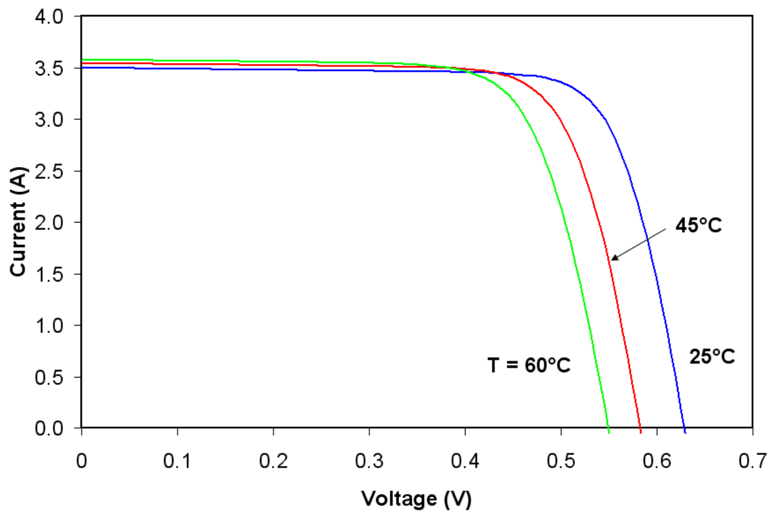
Thermal	RAOG determines level of ventilation / temperature control of PV module & roof materials – ***lets examine this some more…***



Thermal Impact of Low Roof-Array Offset Gap (BIPV Systems)



High Temp Impact on PV Efficiency:

- **cSi - loses ~0.5% ή / º C**
- **aSi - about ½ cSi**
- **CIGS - ~ 0.4% ή / º C**

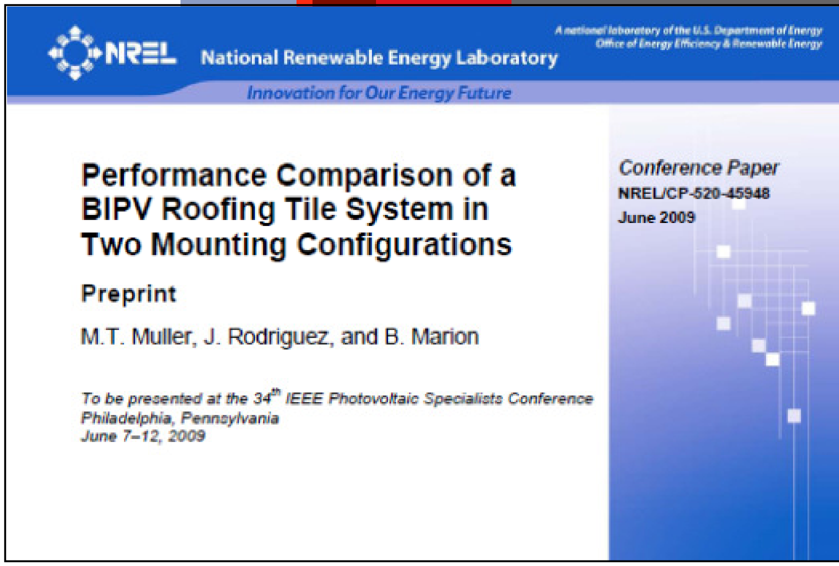
Could lose 30+% of rated PV efficiency on hot day, just when you need it most!

Increase in Roof / Attic Temperature

Thermal Degradation: Arrhenius Equation & aging studies on roofing membranes indicate that aging rate doubles for every 10 ºC temperature rise

So what's the impact of BIPV systems??

NREL Study - 2009


NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

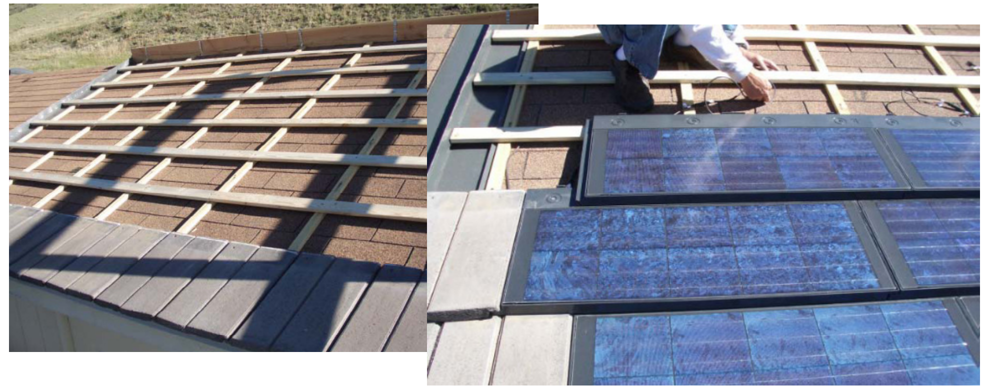
Performance Comparison of a BIPV Roofing Tile System in Two Mounting Configurations

Preprint

M.T. Muller, J. Rodriguez, and B. Marion

To be presented at the 34th IEEE Photovoltaic Specialists Conference
Philadelphia, Pennsylvania
June 7–12, 2009

Conference Paper
NREL/CP-520-45948
June 2009



Direct Mount vs. Counter-Batten Mounted of cSi BIPV Tiles

- Installed side by side on same attic in Colorado

- Counter-Batten Design:

- allowed for airflow below concrete tiles and PV panels
- demonstrated temperatures up to 10℃ cooler than direct mounted modules during high irradiance
- produced 3.4%-4.9% more DC power overall than direct mount
- Is this justified by the cost of the counter-battens? What's the balance?

ANALYSIS AND MONITORING RESULTS OF A BIPV SYSTEM IN NORTHERN ITALY

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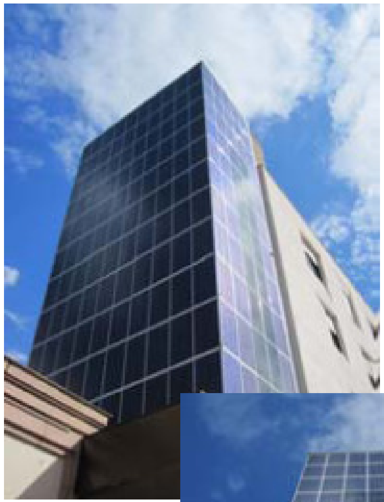
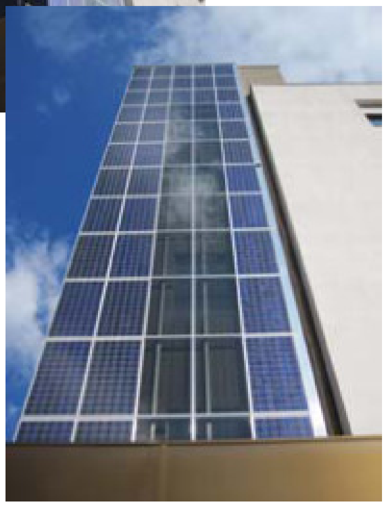




Façade (BIPV) Mounted Photovoltaics

- 6 Months of monitoring in Italy
  - February through July 2010
- Non ventilated system
- Recorded peak module temperature during summer of 57.4℃
  - A loss of 15.4% power generation at this temperature
  - Authors Referenced: Other façade BIPV's have reached peaks of 85℃

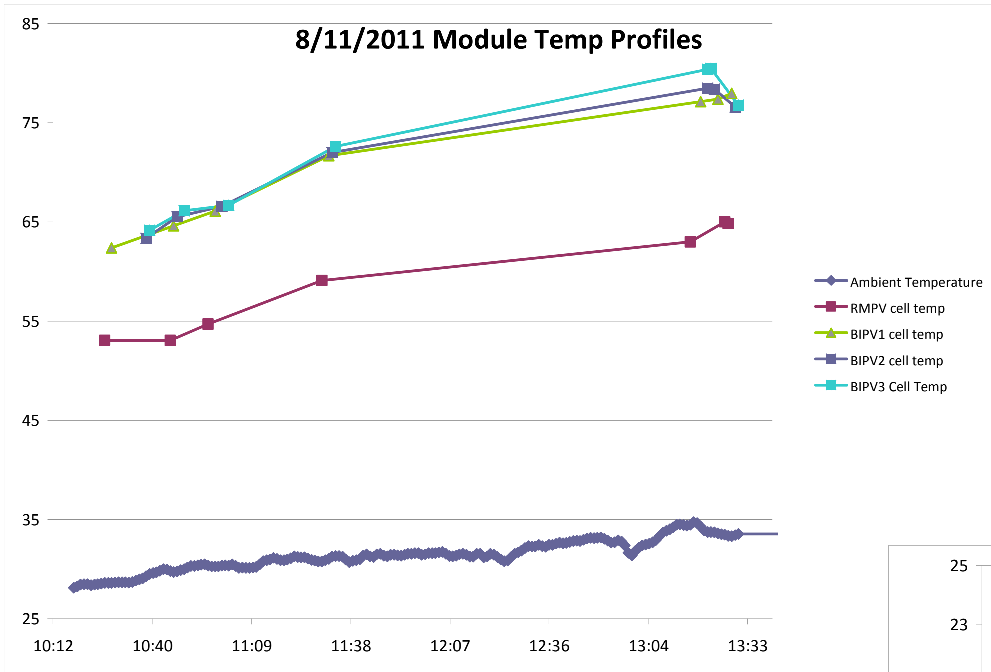
Photovoltaic / Roof Integration – "Worst Case" Thermal Impact of BIPV

Neal Pfeiffenberger, Keenan Watson, Tony Zatkulak, Jim Katsaros

Test Roof configurations:

1. Roof mounted PV (RMPV) control with 4" Roof-array offset gap / fully ventilated attic
2. BIPV1 (0" Roof-array offset gap) with fully ventilated "unconditioned" attic
3. BIPV2 (0" Roof-array offset gap) with "partially-conditioned" sealed attic (insulated at attic floor) / 1" ventilation gap below deck
4. BIPV3 (0" Roof-array offset gap) with "fully-conditioned" sealed attic (insulated at roof rafters) / 1" ventilation gap below deck

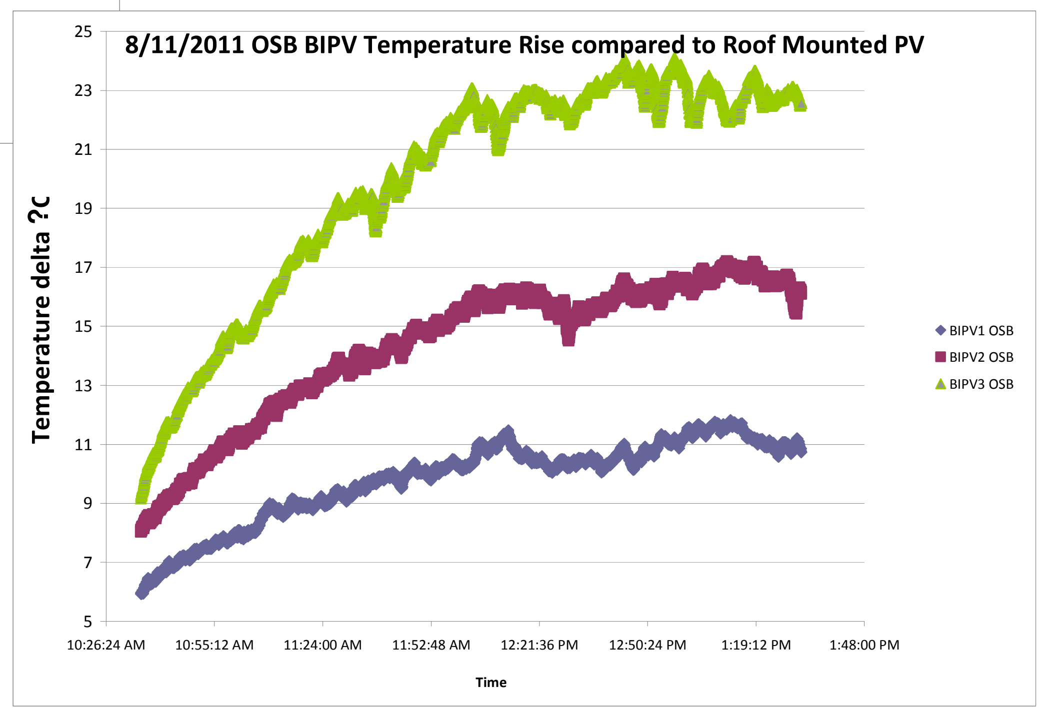
Preliminary Test Results….on a very hot sunny day



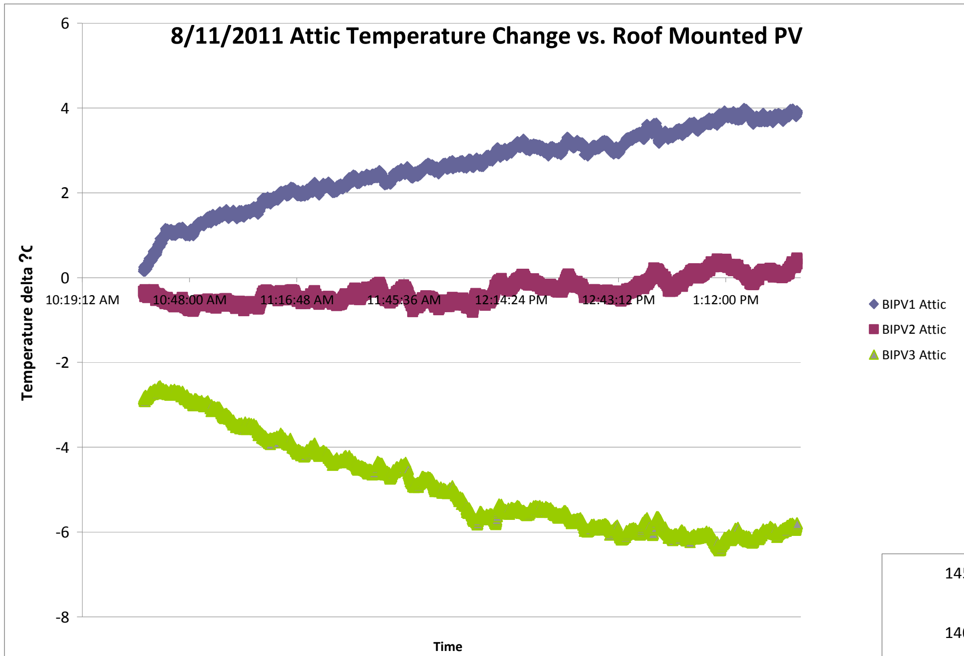
BIPV Modules Temperatures were 15-20 ºC higher than Roof Mounted PV Control – peaked at ~80 ºC (176 ºF)

Roof Deck Temp: BIPV systems 11-23ºC higher than Roof Mounted PV Control

Fully Conditioned Sealed attic had highest gain

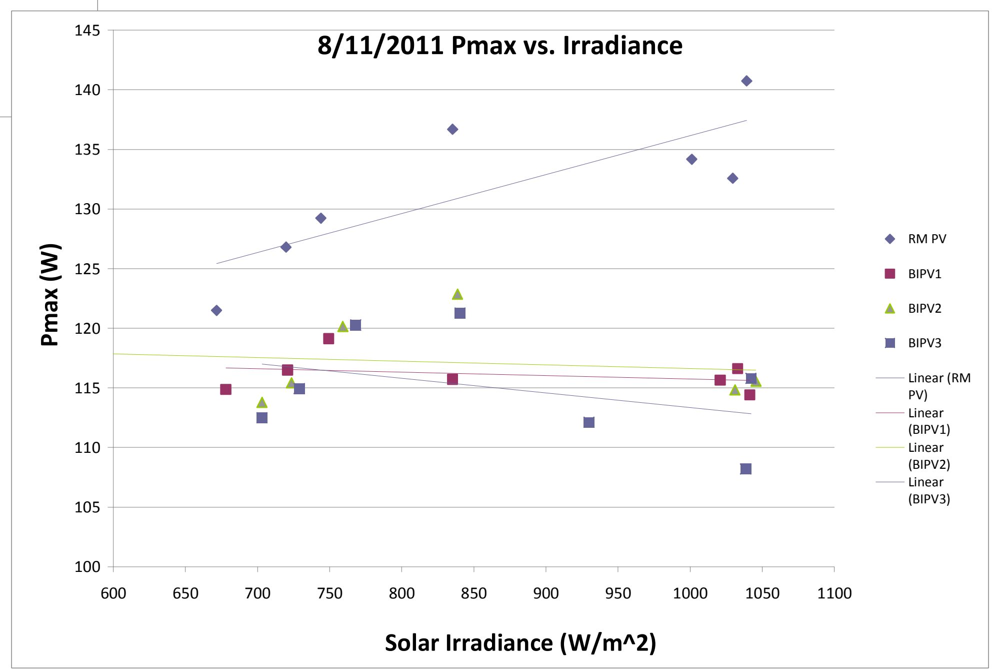


Energy Consumption vs Production – Finding the Right Balance?

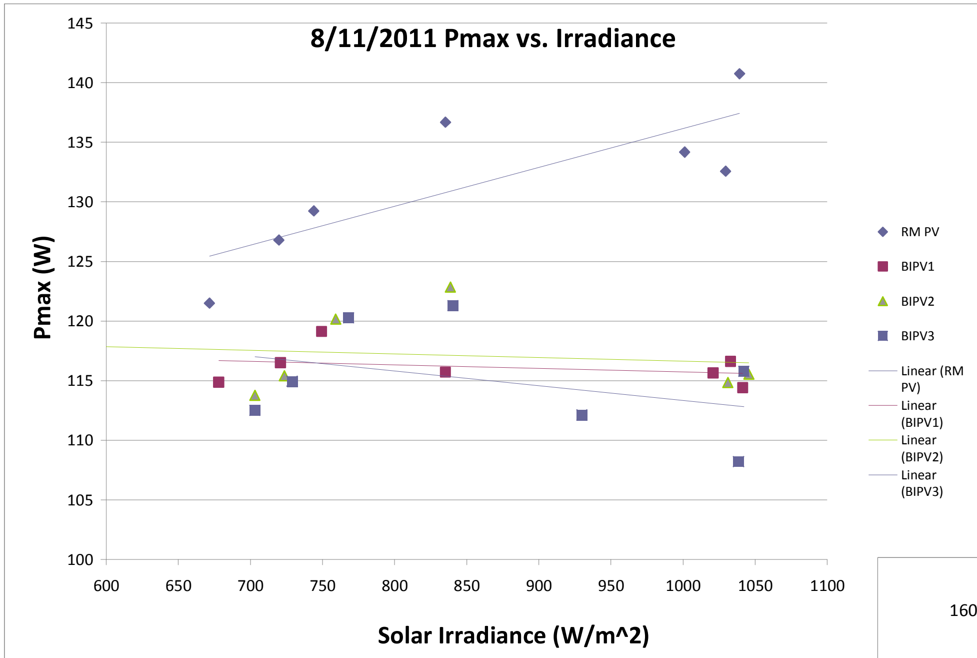


BIPV Attic Temp Difference (compared to Roof Mounted Control): Unconditioned Attic shows moderate temperature rise, whereas Fully Conditioned Attic Temp is cooler than all other systems

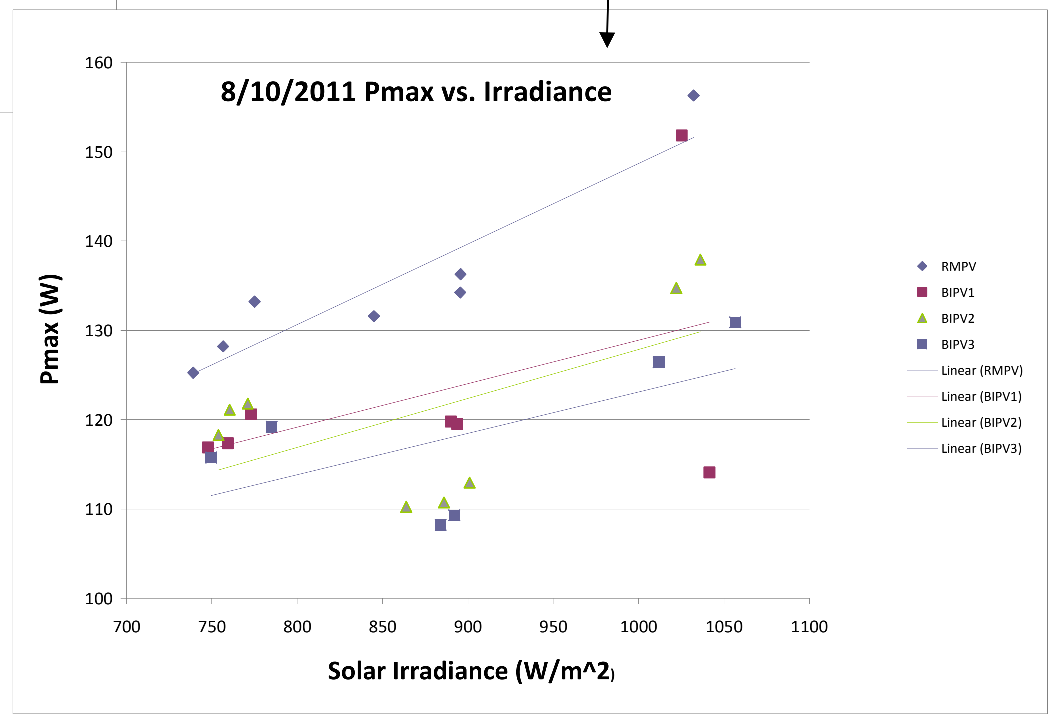
PV Output (Pmax) of Roof Mounted Control about 15-20% higher than the BIPV systems (~115 Watts) at high Irradiation (1000+ W/m2)



Reduced BIPV impact on a cooler day…



On a cooler day with similar irradiance, see a positive trend with Pmax vs Irradiance for all systems, but still a ~15% reduction in PV output for the BIPV Systems



Examples of Building Envelope Tradeoffs with PV Installation Features

Installation Features	Benefit to PV Module	Potential Adverse Effects on Roof System
Mechanical fasteners to secure PV array	Meets structural and wind-load requirements	Moisture intrusion, damage to structural members
Installation of flashing components under roof shingles and tiles	Protects against water intrusion through roof fasteners; integrates with shingling of roof system	Damage caused to existing roof shingles/tiles? Effects on service life and warranty of roof?
Adhered PV system to secure to low-slope roof system	Meets structural and wind-load requirements; minimal roof penetrations	Reduced roof membrane service life? Uncertain service life of adhesive system
Ballasted PV system on low-slope roof system	Meets structural and wind-load requirements; minimal roof penetrations	Structural degradation / abrasion of roof surface / sagging, resulting in roof damage and/or water ponding
Lightweight/composite array racking/module framing system	Reduced structural loads, snap-fit design can reduce installation time and labor	Service life and durability of composite system; combustibility effects / wind load issues?
High offset gap (4+ inches) between array mounting structure and the roof system	Ventilation to limit module temperature rise; enhanced access for roof maintenance and drainage of debris	Increased structural and wind-uplift requirements; air channeling effects on flame spread rating? Poor Aesthetics.
Low offset gap (less than 2 inches) between array mounting structure and the roof system	Enhanced aesthetics (building integrated), less effect of flame spread (adverse effects on module efficiency)	Thermal effect–higher temperature exposure may reduce service life of roofing materials and PV module

Summary

- Roof Mounted PV / BIPV Systems can have a significant impact on the overall performance of the Building Envelope
- More detailed specifications / guidelines are needed to help standardize the installation requirements, including the implications of the Roof-Array Offset Gap
- There are inherent Energy Balance Tradeoffs for Various Roof / PV Configurations
- Real time performance data is needed to better understand optimum balance of thermal / PV performance for various roof configurations

Thank you!