
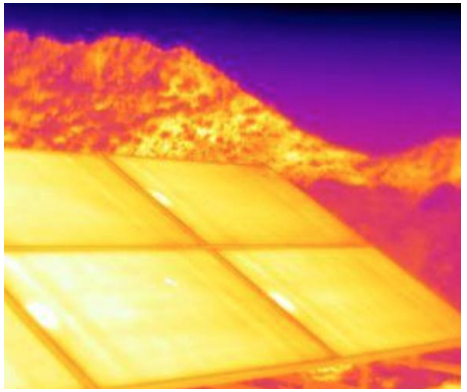
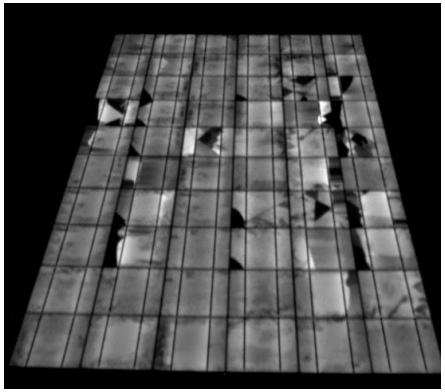


Performance and Durability of Roof-Mounted and Ground-Mounted Solar Modules in India

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National Centre for Photovoltaic Research and Education

Indian Institute of Technology Bombay

presented at

7th WRETC - August 22, 2016

Outline of the Talk

- Introduction
- All-India Surveys of PV Module Degradation
- Results of Surveys
- Relative Performance of Roof-Mounted and Ground-Mounted Systems
- Summary and Implications

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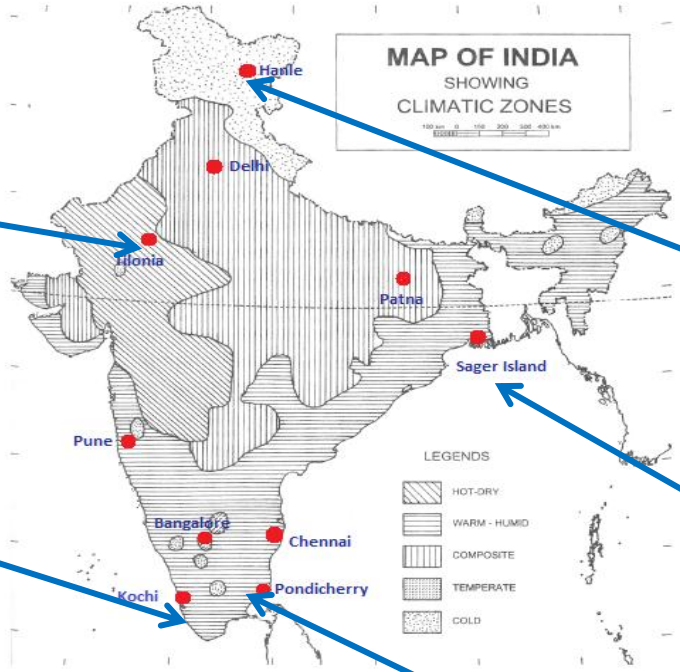
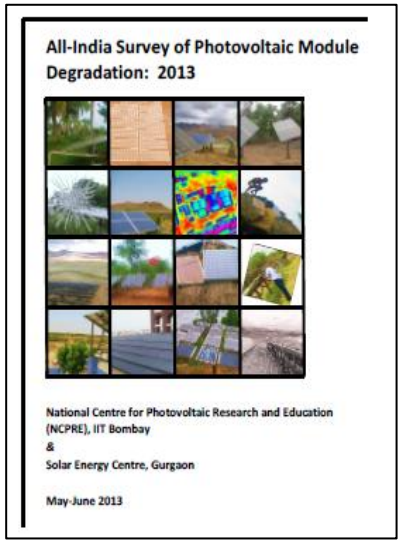
Module Reliability Activities at NCPRE (National Centre for Photovoltaic Research and Education)

- NCPRE established in 2010; activities in silicon and thin film solar cells, new materials, power electronics, grid connectivity, storage and module reliability

- One of the activities undertaken under **module reliability** are the All-India Survey of PV Modules in 2013, 2014 & 2016 (jointly with NISE)

All India Survey of PV Modules – 2013





Download report from

http://www.ncpre.iitb.ac.in/uploads/All_India_Survey_of_Photovoltaic_Module_Degradation_2013.pdf

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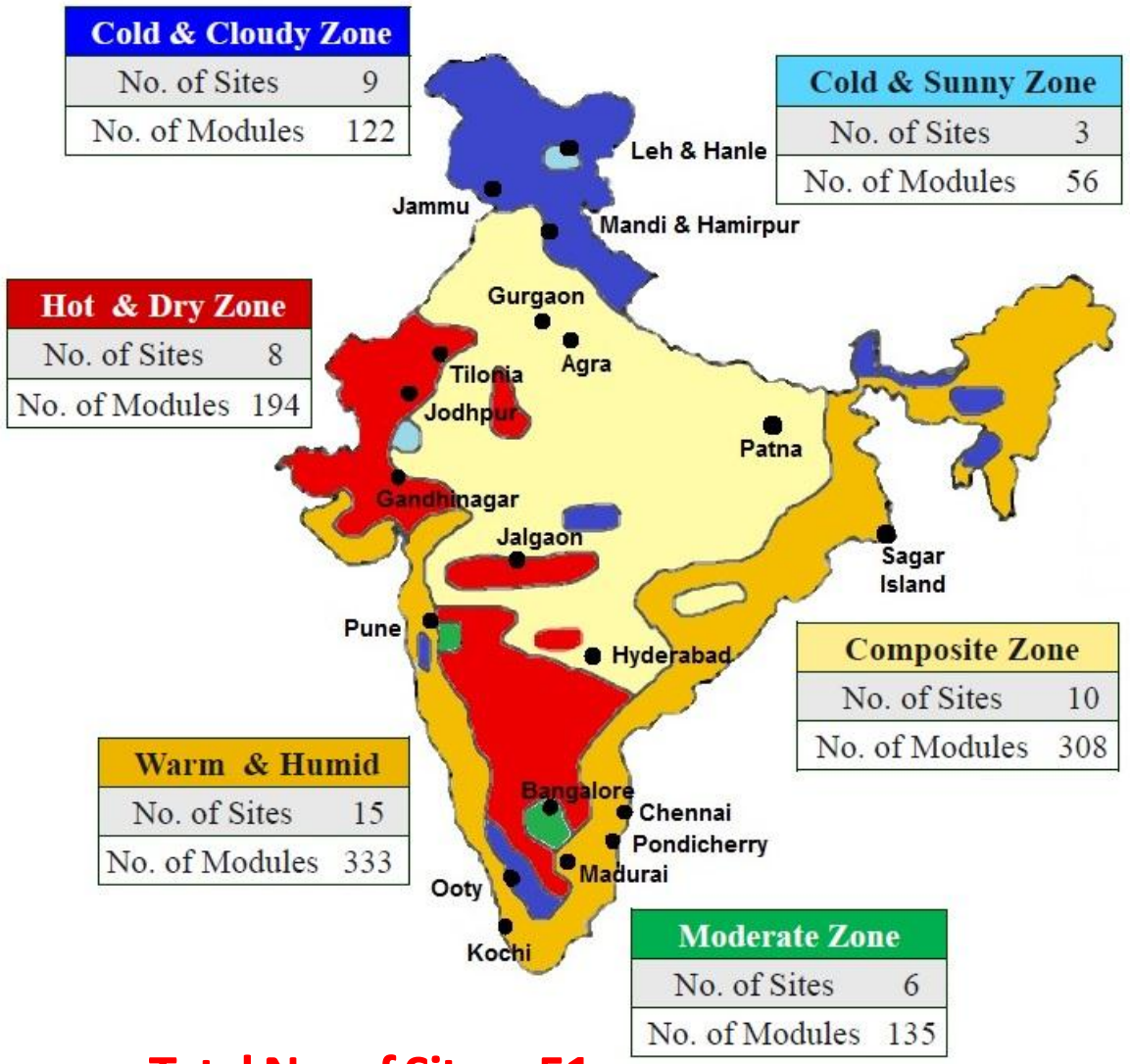
All India Survey of PV Modules – 2014



Characterization Techniques Used
Illuminated *I-V* and Dark *I-V* tracing
Illuminated IR and Dark IR imaging
Daylight Electroluminescence imaging
Interconnect failure test
Insulation resistance test
Visual degradation checklist
Inverter performance test
Socio-economic checklist

Total No. of Sites: 51

Total No. of Modules: 1148

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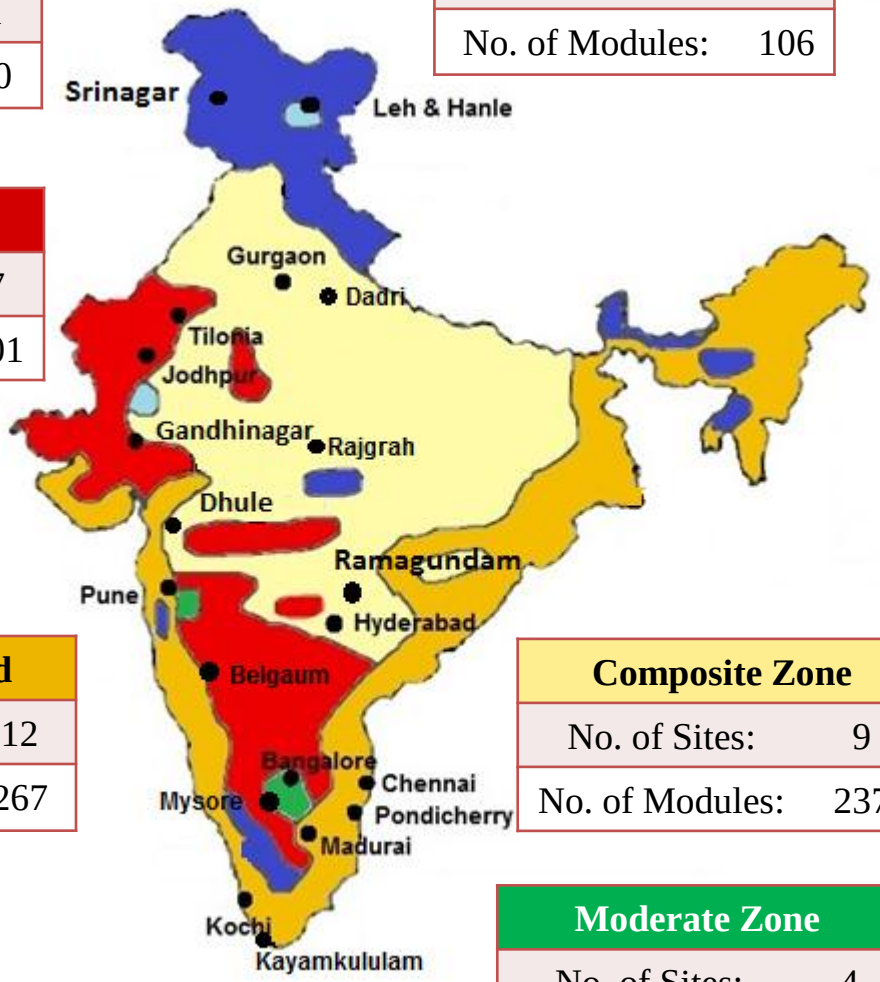
All India Survey of PV Modules – 2016

Cold & Cloudy Zone	
No. of Sites:	1
No. of Modules:	20

Cold & Sunny Zone	
No. of Sites:	4
No. of Modules:	106

Hot & Dry Zone	
No. of Sites:	7
No. of Modules:	201



Warm & Humid	
No. of Sites:	12
No. of Modules:	267

Composite Zone	
No. of Sites:	9
No. of Modules:	237

Moderate Zone	
No. of Sites:	4
No. of Modules:	94

Characterization Techniques Used
Illuminated *I-V* and Dark *I-V* tracing
Illuminated IR and Dark IR imaging
Daylight Electroluminescence imaging
Interconnect failure test
Insulation resistance test
Visual degradation
Inverter performance test
Socio-economic checklist
On-site temperature co-efficient measurement

Total No. of Sites: 37

Total No. of Modules: 925

Survey Sample Details

	2013	2014	2016
No. of Sites visited	26	51	37
No. of Modules surveyed	63	1148	925
Climatic zones	5	6	6
Module Technologies	c-Si, CIGS & a-Si	c-Si, CIGS, CdTe, a-Si & HIT	c-Si, CIGS, CdTe, a-Si & HIT
Age Range	0.5 – 30 years	1 – 30 years	2 – 30 years
Size Range	75 Wp - 500 kWp	75 Wp - 35 MWp	2 kWp - 50 MWp
Rooftop Modules (% of Total)	46	56	41

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Survey Sites

Sites included small, medium and large installations, both ground-mounted and roof-mounted

Survey Team and Equipment

Survey team from NCPRE and NISE

Contributors to All India Surveys

NCPRE: Rajiv Dubey, Shashwata Chattopadhyay, Vivek Kuthanazhi, Jim John, Firoz Ansari, S. Rambabu, B. M. Arora, Anil Kottantharayil, K. L. Narasimhan, and Juzer Vasi

NISE: Birinchi Bora, Yogesh Kumar Singh, Kamlesh Yadav, Manander Banger, Ramayan Singh and O. S. Sastry (NISE)

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NISE
National Institute of Solar Energy

Field Measurements

- Electrical Parameters – **P_{max}**, I_{sc}, V_{oc} and FF
- Annual degradation rates (%/year) of all these values, and especially P_{max}. **Typical value for P_{max} is ~ 1%/year**
- Visual degradation
- Electroluminescence and IR
- Interconnect integrity
- Insulation resistance

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Definition of Degradation

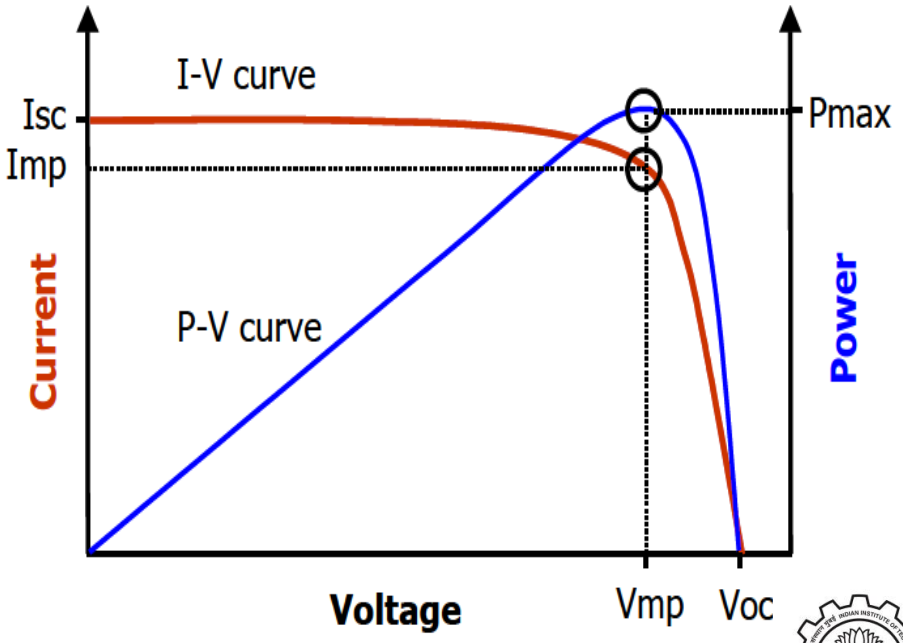
Annual Degradation Rate (%/year) of a parameter Y is calculated by

$$\textbf{Degradation rate of Y (\%)} = \frac{(Y_{nominal} - Y_{present}) \times 100}{Y_{nominal} \times \text{age of the module}}$$

Here, Y can be

- **Power P_{max}**
- Short Circuit Current I_{sc}
- Open Circuit Voltage V_{oc}
- Fill Factor FF

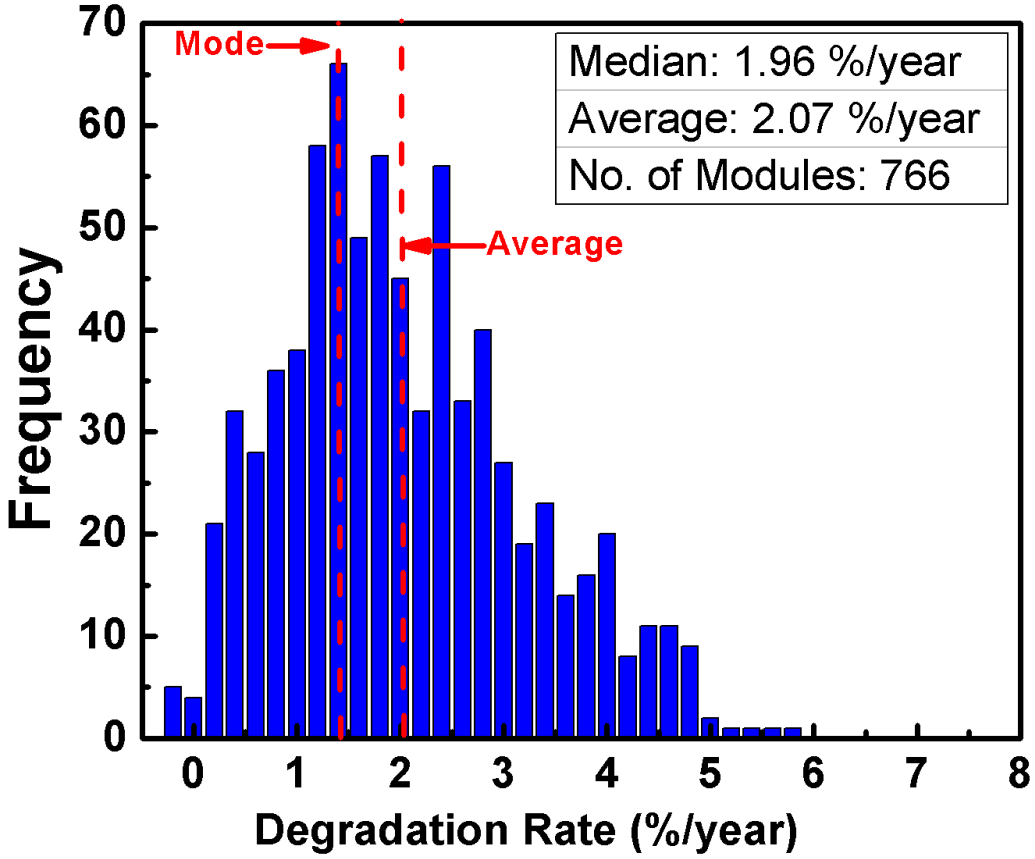
"Nominal" means nameplate value including nameplate tolerance



Errors and uncertainties due to:

- *Instrument Error*
- *Error due to translation to STC*
- *Nameplate uncertainty*

Power Degradation Rates



- **Wide dispersion** in degradation rates
- Need to understand this wide dispersion at a fine-grain level

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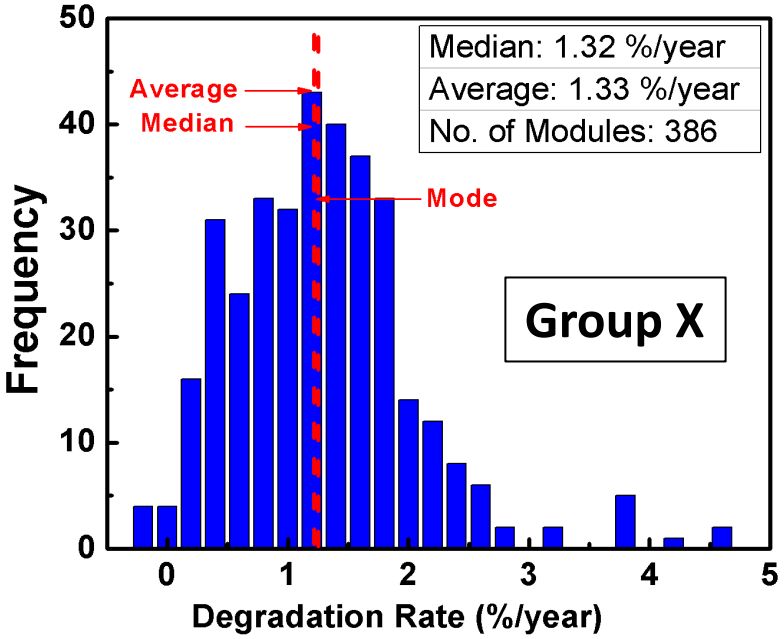
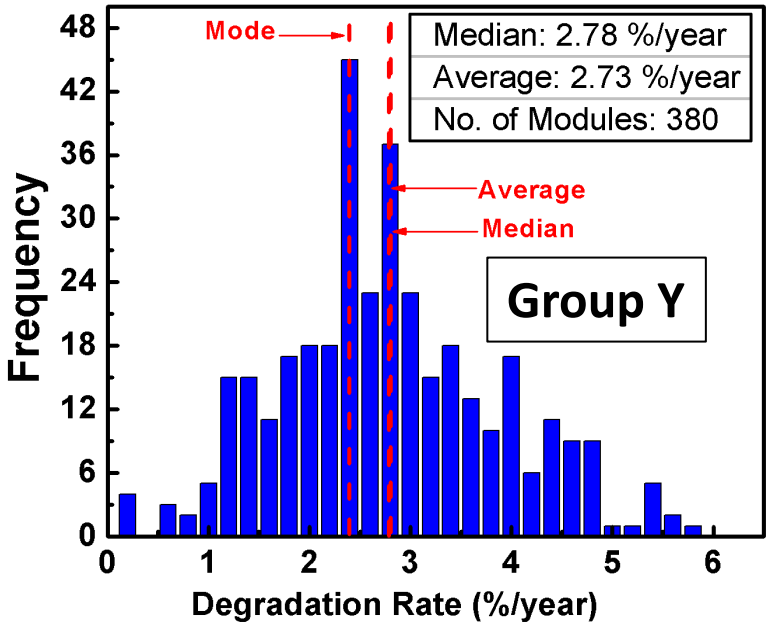
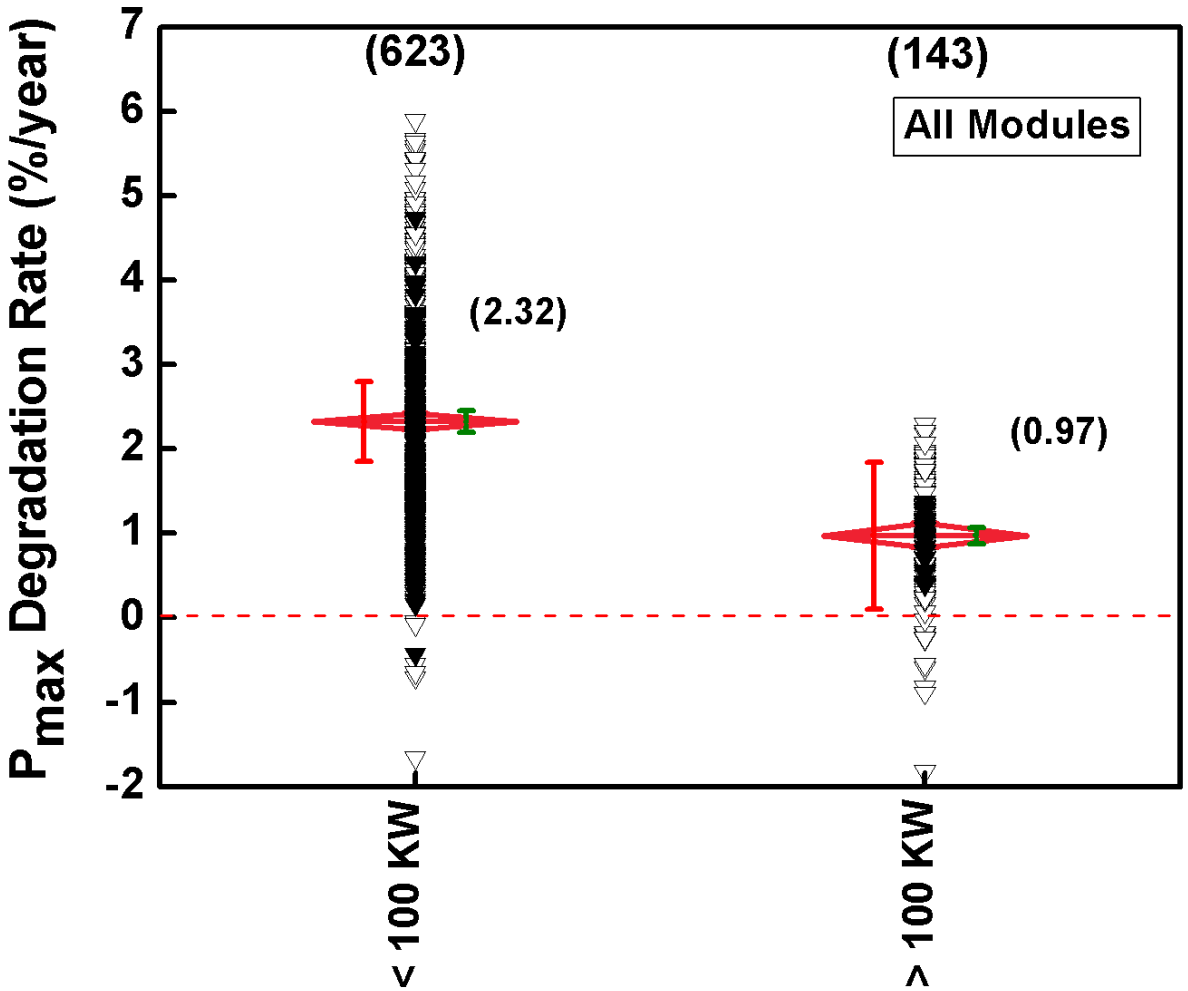
Power Degradation Rates for Modules in Group X and Group Y Sites





- **Group X** sites are quite good ~ **1.3%/year**
- **Group Y** sites are cause for concern ~ **2.7%/year**
- Differences may be due to **module quality**, and also **installation practices**

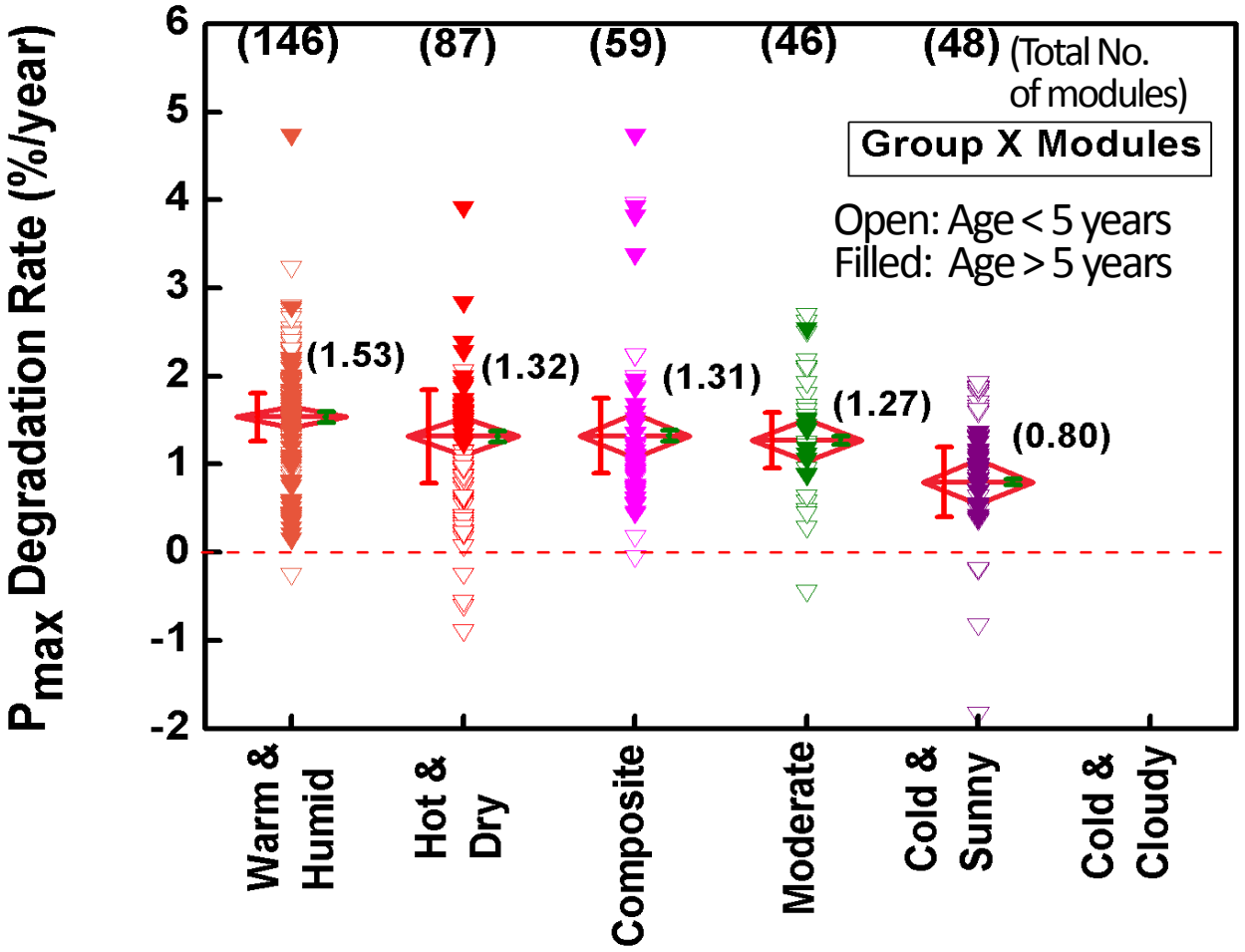
P_{max} Degradation as a function of size – 2014



Points to note:

- **Large size sites perform much better** than small size sites
- Average for large sites is **< 1%/year**
- All Large size sites fall in **Group X**
- May indicate that larger sites, being more professional, exercise 'due diligence' in module selection and installation

P_{max} Degradation for different Climatic Zones – 2014



Points to note:

- **Tight** distributions
- Degradation rate numbers are **reasonable**
- Climatic zone variations
- **Hot climates show higher rates**
- Cold climates show good rates

Data for individual modules (# of modules in parentheses on top). Horizontal red bar is the mean. Error bar on right side due to instrument plus translation. Error bar on left is due to nameplate uncertainty.

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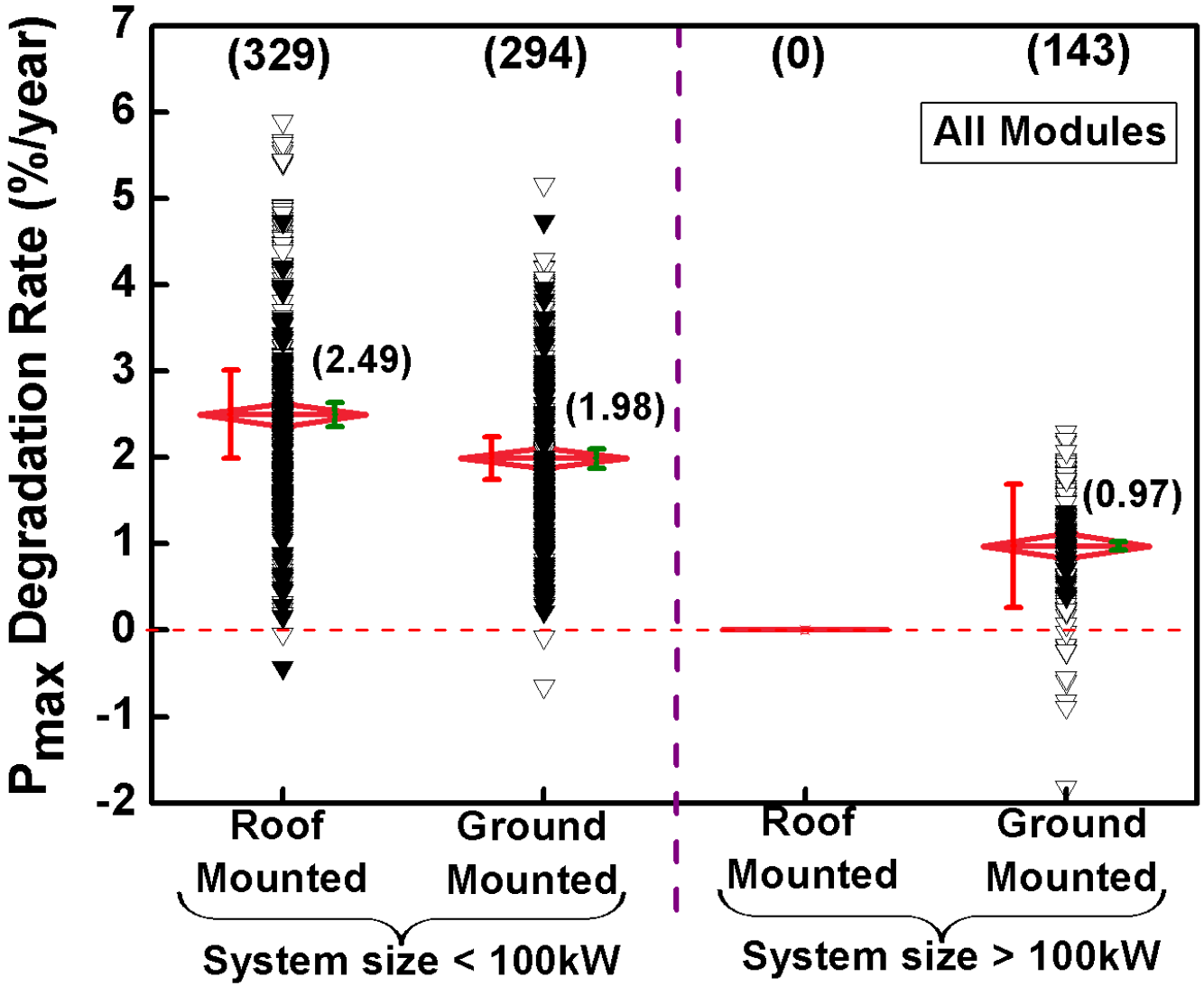
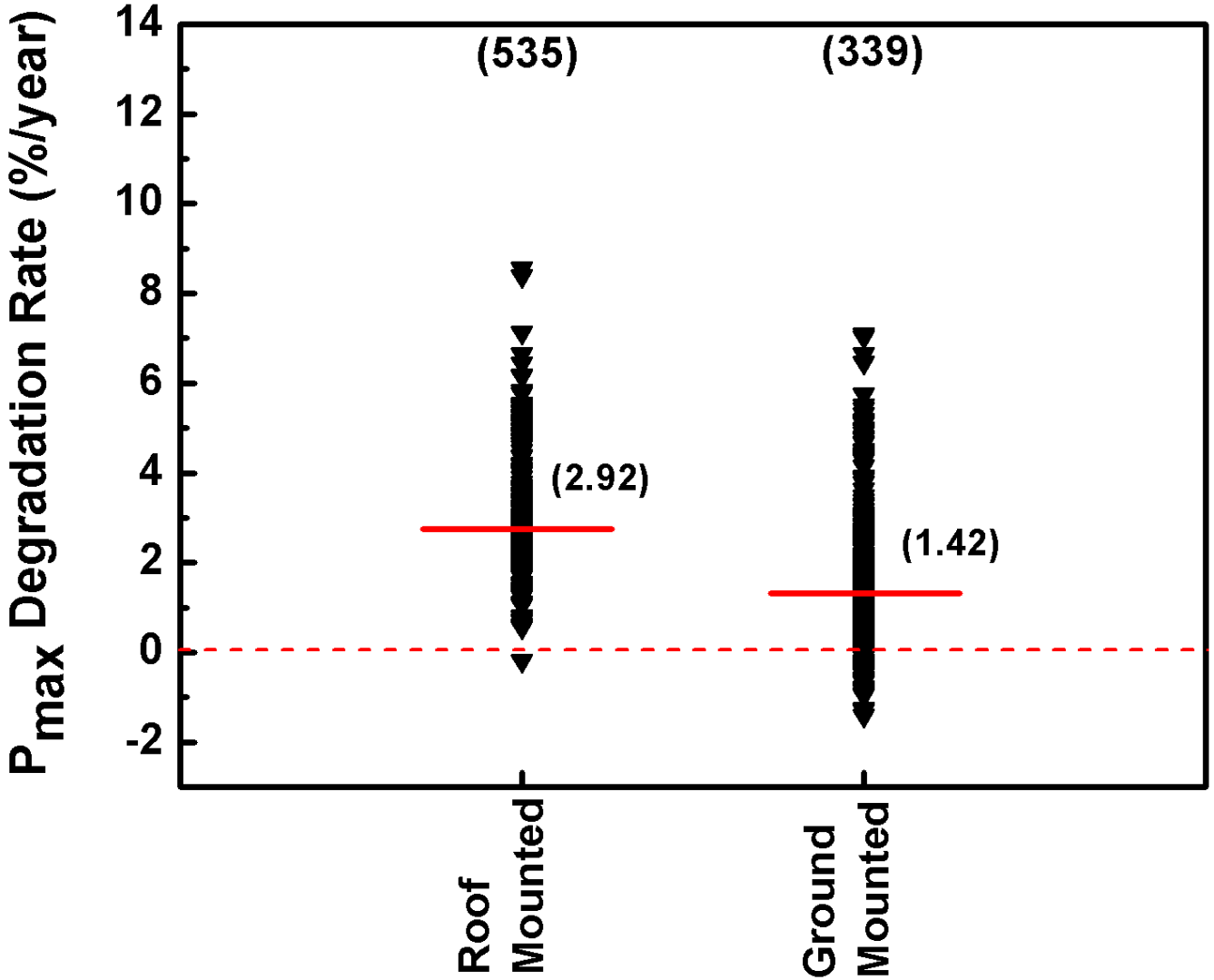
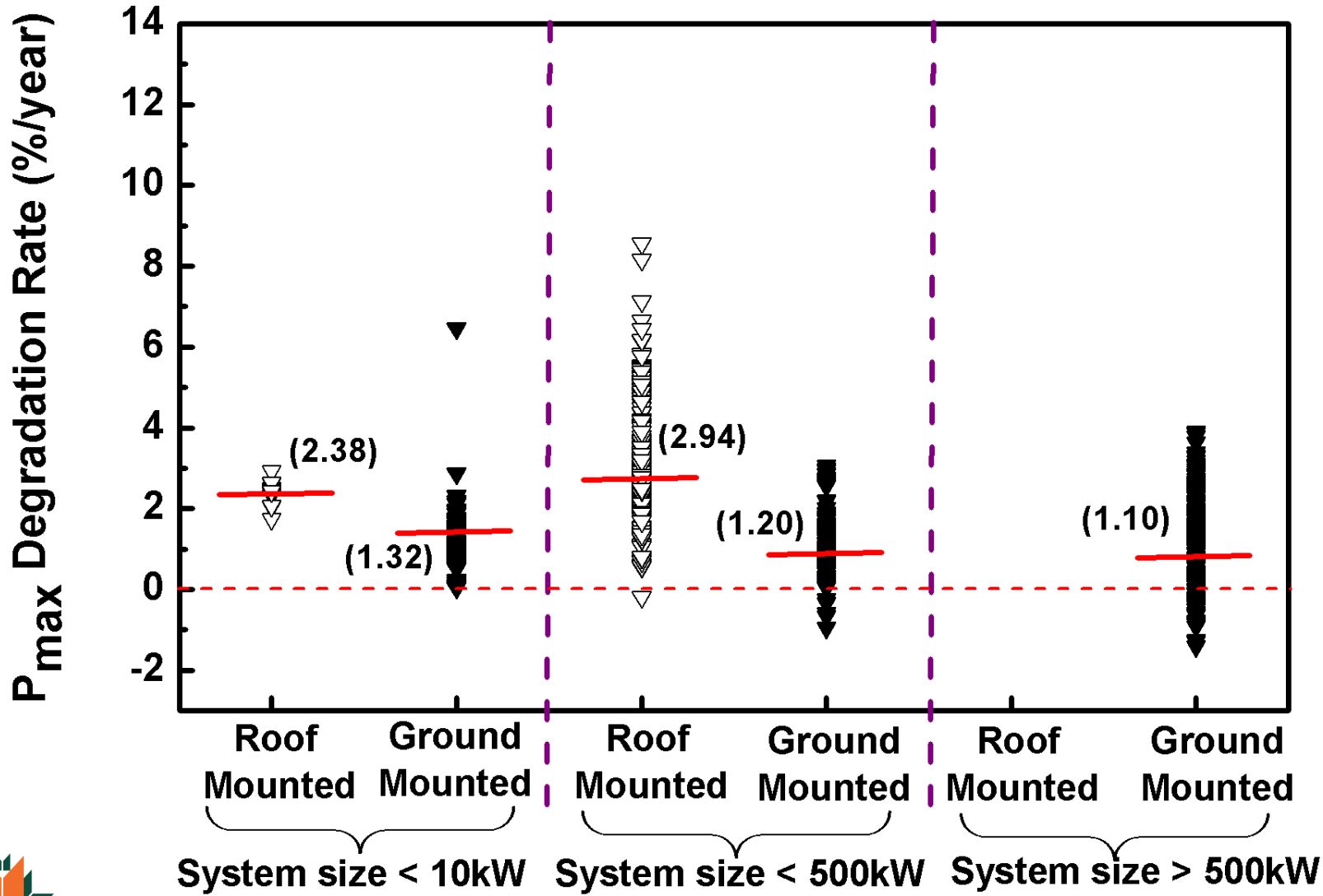
P_{max} degradation for ground / roof mounted – 2014



P_{max} degradation for ground / roof mounted – 2016



P_{max} degradation for ground / roof mounted – 2016



Possible reasons for higher degradation rates for roof-mounted modules

- **Roof-mounted systems run hotter than ground-mounted**
  - Less air flow; typically less clearance
  - Clearance distance determines temperature
  - Higher temperatures cause hot cells, faster EVA degradation, faster corrosion, etc. leading to higher degradation rates
- **Roof-mounted systems tend to be less professionally installed**
  - Handling issues generate microcracks which can result in higher degradation rates
  - Smaller rooftop systems may compromise on cost and quality of modules

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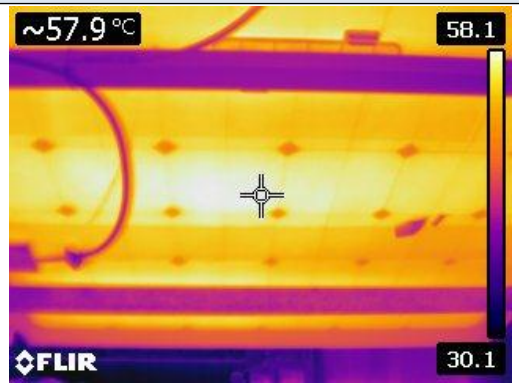
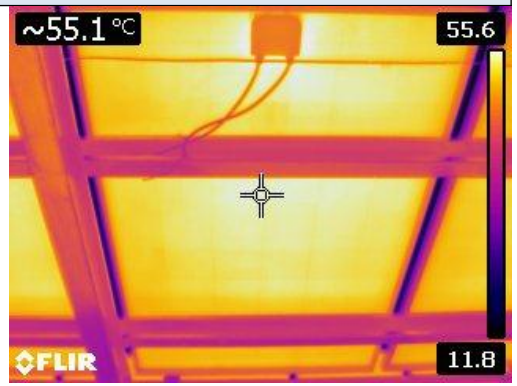
Influence of Mounting Height on Module Temperature at IIT Bombay

Day	c-Si Module Temperature (°C)		
	Height = 30 cm [1]	Height = 83 cm [2]	Height = 149 cm [3]
1	59.2	58.7	57.7
2	59.4	57.5	57.8
3	56.8	55.5	56.2
4	58.3	57.0	56.0
5	58.8	57.0	56.0
Average	**58.5**	**57.1**	**56.7**
NOTE: All module temperatures were recorded at noon, at irradiance of 760 W/m^2.			





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Simulation Study by G. Pallardo (Sweden)

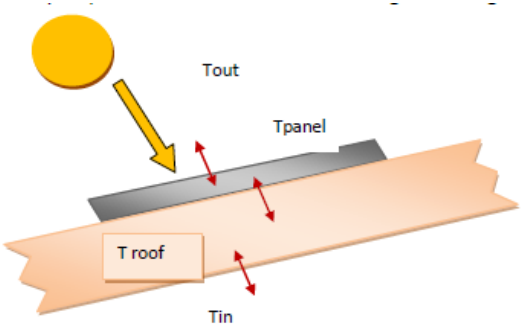


Figure2: PV installation without ventillation

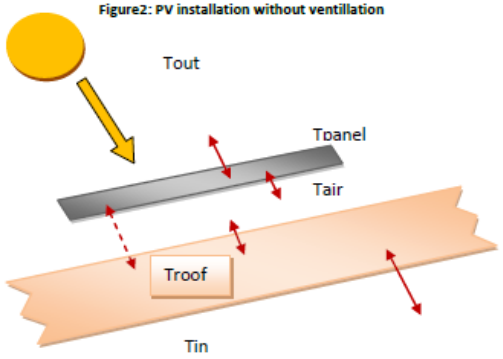


Figure 3: PV installation with ventillation

Conditions	T cells [ºC]	T roof[ºC]
Cold day	34.9	21,65
Temperate day	51.03	34.54
Warm day	60.52	35.2

Table 2: Results without ventilation

Conditions	T cells	T roof
Cold day	8,3	20,9
Temperate day	24,7	21
Warm	43,5	21,1

Table 3: Results with 10 cm ventilation

Conditions	T cells[ºC]
Cold day	5.325
Temperate day	25.325
Warm day	45.325

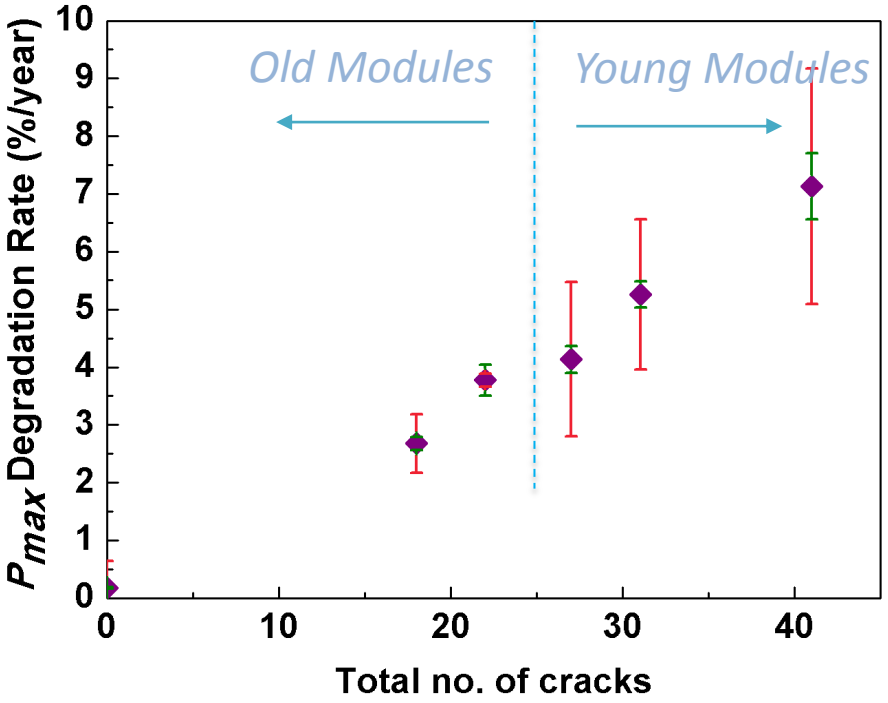
Table 4: Results with 50 cm ventilation

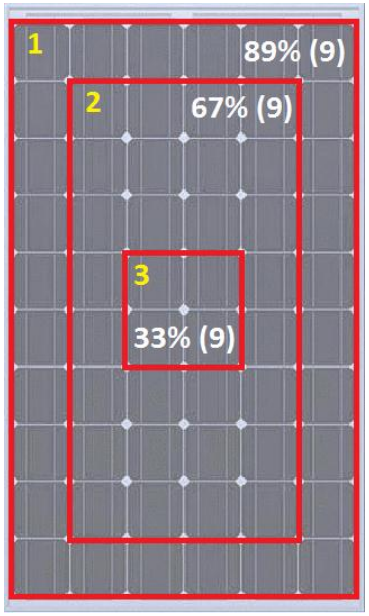
RESULT:

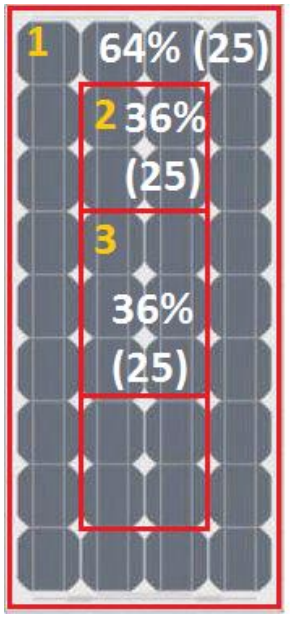
- Module kept directly on roof is 17 ^{o}C hotter than module with air gap of 10 cm.
- Module temperature is similar for air gap of 10 cm and 50 cm.

Ref:
http://www.ht.energy.lth.se/fileadmin/ht/Kurser/MVK160/2011/EFFECT_OF_VENTILATION_IN_A_PHOTOVOLTAIC_ROOF_Guillem.pdf

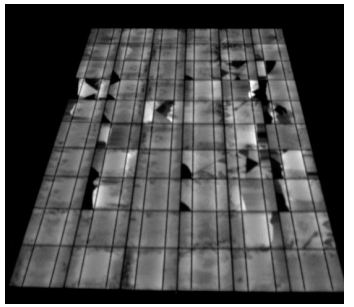
Field Daylight Electroluminescence – 2014





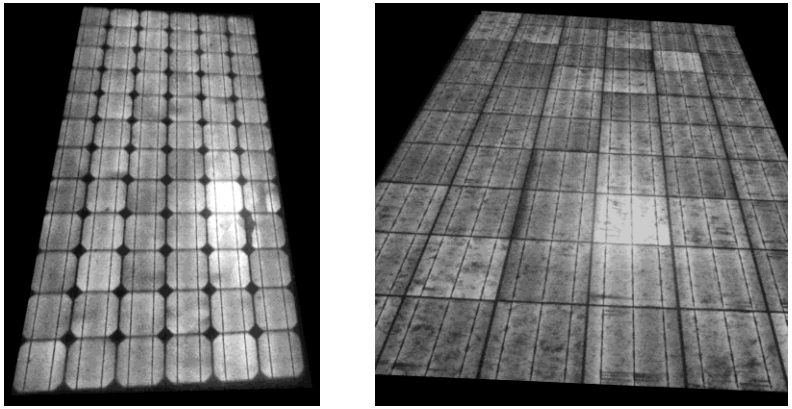


- P_{max} degradation in these cases related to FF losses
- More occurrence of cracks in cells near the edges – transportation, handling

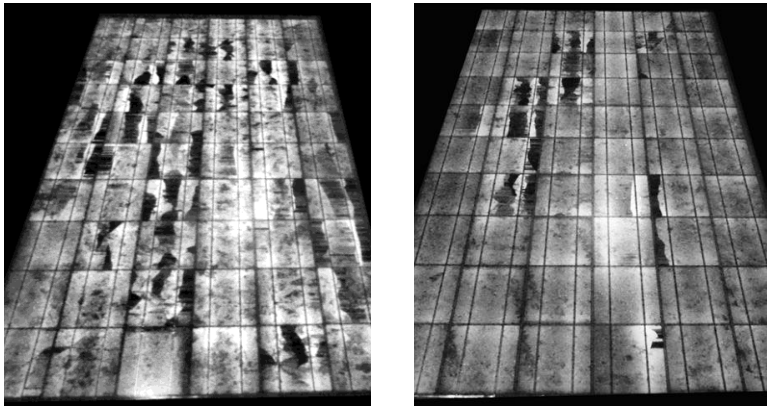


Field Daylight Electroluminescence (EL) for ground- and roof-mounted modules – 2016

Type of installation	No of modules having cracks	Total no of modules	Percentage of modules affected by cracks
Ground-Mounted	42	125	33.6
Roof-Mounted	95	133	71.4



Ground-mounted



Roof-mounted

Summary and Implications

- The **All-India Surveys of PV Modules,** as well as other data, have given valuable information about the health and durability of PV modules under different conditions
- **Wide dispersion** in power degradation rates (% / year) seen; some sites show good performance; other sites cause for concern
- **Climatic variation** shows that modules in Hot zones show high degradation
- Modules in **large ground-mounted systems degrade at ~ 1 %/year**
- **Rooftop-mounted modules** on the average are seen to **degrade faster** than ground-mounted modules
- To ensure success of the **40 GW rooftop program,** due attention must be paid to **module selection, installation procedures,** and **design of mounting systems**
- For smaller off-grid rooftop installations, the degradation rates may not be very relevant

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Acknowledgments

Ministry of New and Renewable Energy (MNRE), Government of India, is gratefully acknowledged for funding NCPRE and the Survey.

The authors also acknowledge the help and assistance received from many people at the sites surveyed.

Publications on All-India Surveys

1. R. Dubey, *et al.,* "Performance Degradation in Field-aged Crystalline Silicon PV Modules in Different Indian Climatic Conditions," 40th *IEEE PVSC*, Denver, USA (2014).
2. S. Chattopadhyay, *et al.,* "Visual Degradation in Field-aged Crystalline Silicon PV Modules in India and Correlation with Electrical Degradation," 40th *IEEE PVSC*, Denver, USA (2014).
3. V. Kuthanazhi, *et al.,* "Linking Performance of PV Systems in India with Socio-Economic Aspects of Installation," 40th *IEEE PVSC*, Denver, USA (2014).
4. R. Dubey, *et al.,* "Daylight Electroluminescence Imaging by Image Difference Technique," 6th *World Conference on Photovoltaic Energy Conversion* and 41st *IEEE PVSC*, Kyoto, Japan (2014).
5. R. Dubey, *et al.,* "Measurement of temperature coefficient of Photovoltaic Modules in field and comparison with laboratory measurements" 42nd *IEEE PVSC*, New Orleans, USA (2015).
6. S. Chattopadhyay, *et al.,* "All India Survey of Photovoltaic Module Degradation 2014: Survey Methodology and Statistics," 42nd *IEEE PVSC*, New Orleans, USA (2015).
7. R. Dubey, *et al.,* "Correlation of Electrical and Visual Degradation seen in Field Survey in India," 43rd *IEEE PVSC*, Portland, USA (2016).
8. G. Tamizhmani, *et al.,* "Comparative Study of Performance of Fielded PV Modules in Two Countries," 26th *International Photovoltaic Science and Engineering Conference*, Singapore (2016).