NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Measuring and Modeling Nominal Operating Cell Temperature (NOCT)

NREL
Test & Evaluation

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Outline

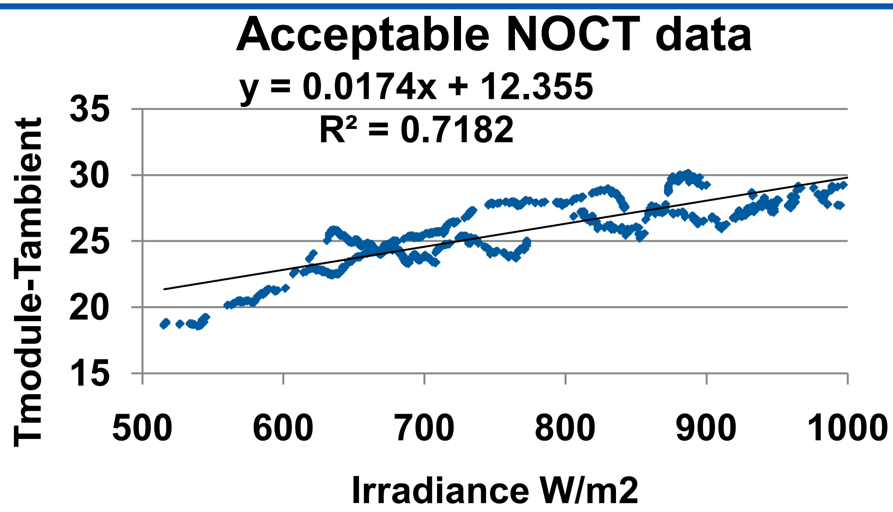
- Overview of NOCT (IEC 61215)
- Motivation for NOCT research
- Basic Heat transfer model in relation to NOCT
- Hypothesis and Testing at NREL
- Results for single module over 8 months
- Side by Side comparison of 3 modules with substantially different reported NOCT values
- Problems with the NOCT procedure
- Unanswered questions
- Conclusions and continuing work

NOCT (800 W/m², 20C, 1m/s)

(IEC 61215 primary method)

- Mount module on an open rack at a 45 degree tilt (Voc)
- Border test module with at least 0.6 m of black aluminum plating or similar modules
- At a 5 s intervals measure the following:
  - Irradiance, Ambient Temp, Cell Temp, Wind Speed, Wind Direction
- Record data before and after solar noon covering at least a 300 W/m^2 range
- Reject the following data:
  - 10 minute intervals after the irradiance varies more than 10% in10 minutes
  - 10 minutes after the wind speed > 4m/s
  - Wind speeds outside 0.25-1.75 m/s
  - Ambient temperature outside 5-35C
  - Wind direction within +/-20˚ of E or W
  - Irradiance<400 W/m2,
  - Data sets in which the ambient temperature varies more than 5C
- For a single day with data meeting the above requirements, plot the modules temperature rise above ambient temperature as a function of irradiance
- Use linear regression to fit the data plotted. Use the regression equation to determine the module temperature rise above ambient at 800 W/m^2.
- Add 20C to determine module temperature at reporting conditions.
- Apply correction factor based on data set average wind speed and ambient temp
- Complete the above procedure for 3 days and then average all three to report NOCT

Example of a Single Day NOCT calculation



61215 © IEC:2005

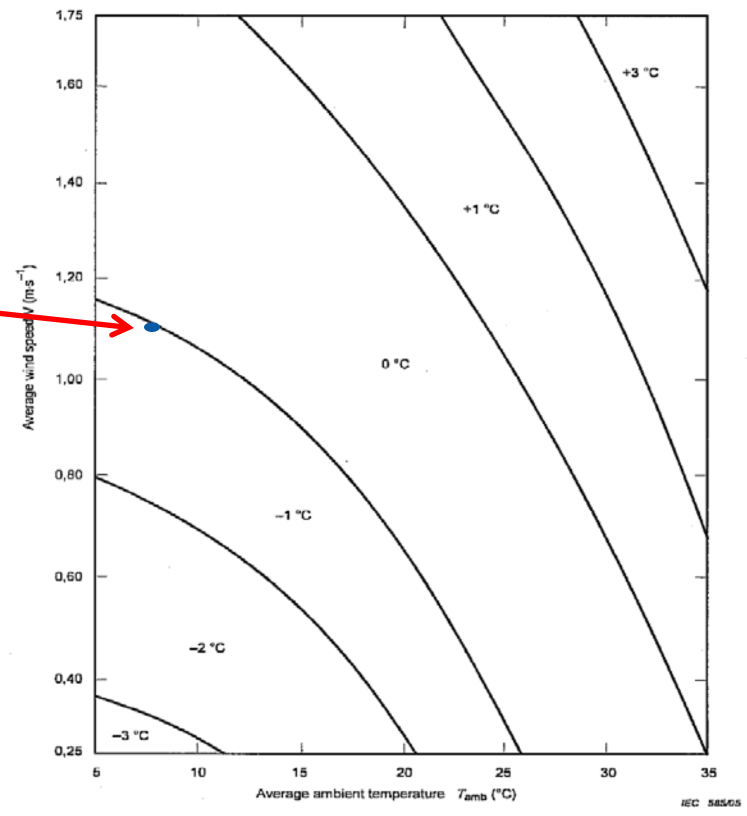
Average Ambient = 7.8C
Average Wind Speed = 1.08 m/s
Correction Factor = (-1 or 0)

NOCT$_{1day}$=**<u>0.0174*800+12.355</u>** + *<u>20</u>* - (1or 0)

Regression equation

20C ambient reporting condition

NOCT$_{1day}$= 46.3 or 45.3

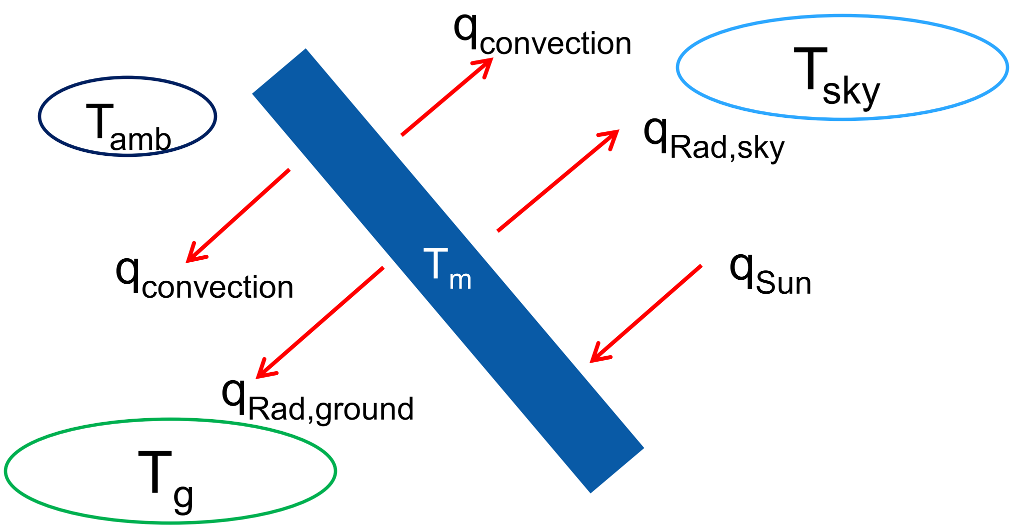


Motivation for NOCT research

- Participate in NOCT round robin testing to understand seasonal and other variation in the NOCT procedure.
- The California energy commission reports NOCT values for rack-mounted standard silicon modules in a glass/Tedlar package that range from 41.6C to 52.3C (these are test results from 3rd party labs)
- A 10.7C variation coupled with a power coefficient of 0.5%/C suggests up to a 5% improvement in power output based on module selection.
- If modules are in open circuit and have the same basic package of materials, heat transfer theory indicates they should reach the same steady state temperature.
- If heat transfer theory is correct, this NOCT research has the potential drive changes in how NOCT is measured or replace measurements with an analytical approach to determining NOCT

Basic NOCT Heat Transfer Model

$\dot{E}_{in} = \dot{E}_{out}$ (steady state, no power produced)



$$\alpha_s G_s = \varepsilon_g \sigma\left(T_m^4 - T_{sky}^4\right) + 2\left(1.2 * W_{avg} + 4.8\right)\left(T_m - T_{amb}\right) + \varepsilon_b \sigma\left(T_m^4 - T_g^4\right)$$

Assumptions for a standard glass front, plastic back silicon PV module

α_s=0.92 (module absorptivity), G_s= (global irradiance on module) ε_g=0.84 (glass emissivity)
σ = 5.67e-8 (Stefan-Boltzmann constant), ε_b=0.893 (back of module emissivity)
T_m, T_{sky}, T_{amb}, and T_g are module, sky, ambient, and ground temperatures respectively
W_{avg} = 5 minute average wind speed,
(1.2*W_{avg}+4.8) data fit for convection heat transfer, applies to W_{avg} ranging from 0-4 m/s

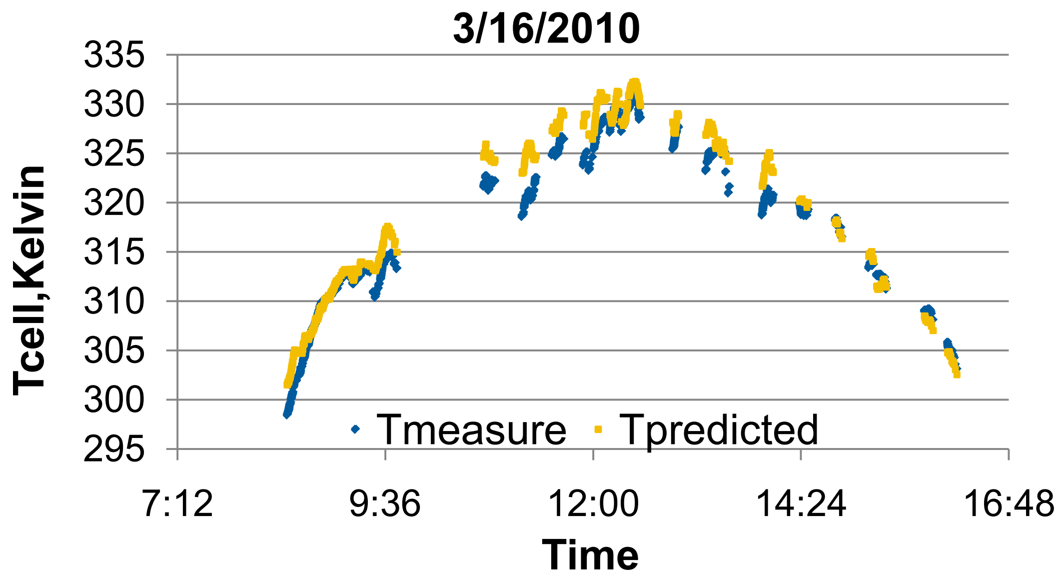
Heat Transfer Model Against NOCT data

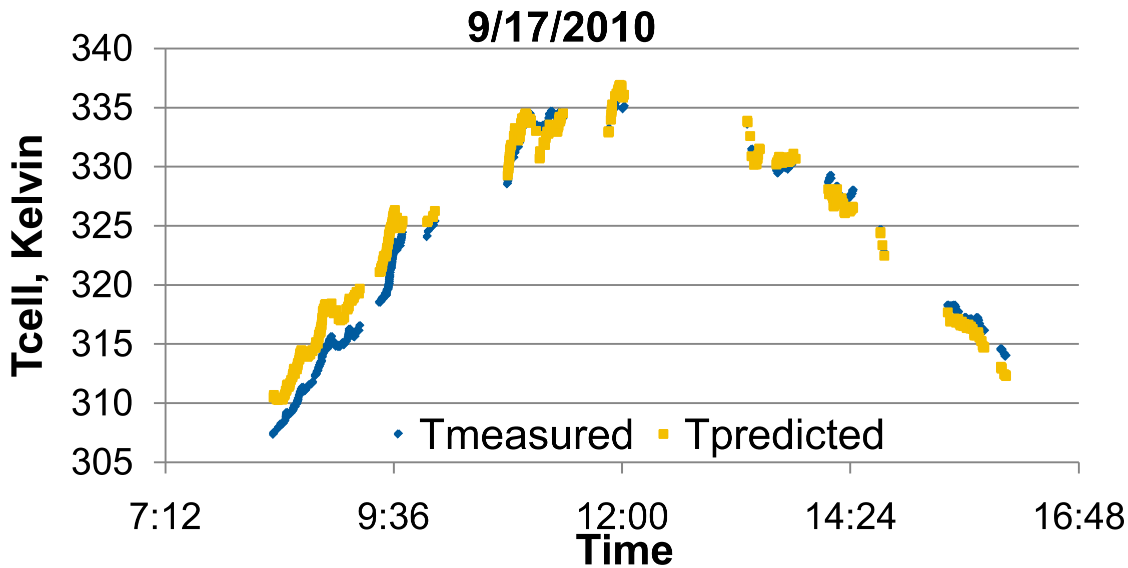
Model inputs

- T_{sky} (site downwelling IR)
- T_g (site upwelling IR)
- T_{amb}
- Wind Speed (5 min avg)
- POA irradiance

•Data gaps occur when NOCT conditions are NOT achieved

•NOCT conditions are an approximation of steady state





Model Used to indicate NOCT variation

Modeled Cell Temperatures under possible NOCT measurement conditions								
	Tsky, C	Tground, C	Tamb, C	Wind (m/s)	Cell Temp, C	Tcell-Tamb, C	Correction	NOCT, C
baseline	-5	20	20	1	47	27	0	47
cold sky	-43	20	20	1	42.5	22.5	0	42.5
hot sky	12	20	20	1	49.8	29.8	0	49.8
cold day	-5	5	5	1	36.7	31.7	-1	50.7
hot day	-5	45	35	1	59.7	24.7	2	46.7
low wind	-5	20	20	0.25	49.1	29.1	-2	47.1
high wind	-5	20	20	1.75	45.2	25.2	1	46.2
NREL winter	-25	5	5	1	33.9	28.9	-1	47.9
NREL summer	10	45	35	1	61.9	26.9	2	48.9

Hypothesis and Testing at NREL

- Based on the basic heat transfer model, the following is hypothesized:
  - 10C variation from NOCT procedure based on varying sky/ground/ambient temperature
  - Modules with a similar package should have NOCTs within 2C of each other
    - Varying module absorptivity by 5%, heat transfer suggests a 1.5C cell temp change
    - Varying glass emissivity by 5%, heat transfer suggests a 0.5 C cell temp change

- A testbed was established at NREL to measure NOCT following the IEC procedure for a single module across all 4 seasons

- Data has been gathered and analyzed from January 2010 to the present.

- In July 2010 two additional glass/silicon/plastic modules were mounted in a side by side configuration with the original module

- Previously reported NOCT values for the three modules are 42.4C, 47.9C, and 52.3C

8 Month Results for Single Module

NOCT TEST DATA -OPEN CIRCUIT, January -September 2010										
Date	1/15	3/12	3/16	3/17	6/15	6/17	6/25	7/26	8/10	9/17
Time(start/end)	9:00-15:35	9:18-16:09	9:29-16:09	9:11-14:07	10:19-16:04	9:09-13:54	7:58-12:36	11:06-15:17	8:12-16:03	11:08-16:02
# data points	898	275	680	121	199	274	287	105	250	322
Ambient Temp C, average	7.8	11.8	14.9	16.9	24.4	26.3	31.1	33.6	27.9	26.1
Wind Speed m/s, average	1.08	1.07	1.04	1.17	1.01	0.94	0.96	1.02	1.16	1.15
Irradiance range W/m^2	517-1037	494-1135	489-1168	806-1106	448-1024	730-1032	468-1012	629-966	508-902	428-1092
Irradiance W/m^2, average	775	727	1009	933	840	876	646	707	646	760
NOCT correction factor, C	-1	0	0	0	0	0	1	2	1	1
NOCT reported	45.3	46.9	46.6	45.3	45.9	45.9	45.4	49.1	49.8	47.9
Note					see*	see*	see*	see**		

* Temperature measurements on the module backskin, assumed cell is 1.3 C hotter at NOCT
** This day only had 5 data points before solar noon

Comments on 8 month Results

- Lowest 3 day average is 45.33 C NOCT
- Highest 3 day average is 48.9 C NOCT
- This is within +/-4C uncertainty associated with the NOCT procedure
- Only 10 days over 8 months suggest procedure is too limited
- Several good days were unusable because the temperature increased more than 5C over the needed irradiance range
- 2 potential days were lost due to measurement problems
- 2 days had to be thrown out due to snow on the ground. Module temperature was elevated by 2 degrees due to irradiance to the back side

NREL Test Results for 3 Modules Reported to Have NOCT Values of 42.4C, 47.9C, and 52.3C

IEC 61215 Side-by-Side Testing				
	7/26	8/10	9/17	3 day Avg
Module 1 NOCT	49.1	49.8	47.9	48.9 C
Module 2 NOCT	49.1	49.7	47.1	48.6 C
Module 3 NOCT	48.5	50.2	47	48.6 C

Note that Module 1 is that reported on for 8 months

Problems with NOCT Procedure

- 10C range of NOCT values for modules that show identical NOCT values in side-by-side testing
- Procedure reported to have +/-4 C uncertainty
- For many locations restricted conditions are difficult to achieve (In Golden, CO 10 NOCT days over 8 months)
- Neglects the heat transfer parameters of sky and ground temperature
- Does not represent temperature of modules under load
- Provides no information about how temperature varies with wind, irradiance, etc
- Test reports from more than one lab indicate procedure is not being followed in all aspects. (An argument to simplify)

Unanswered Questions

- Will the NREL site eventually show the full 10C range of NOCT for the 3 modules under test?
- How are Labs measuring cell temperature with glass on glass modules?
- How much would NOCT vary if the procedure is changed so that the module is under load?
- Changes are being suggested to the IEC procedure. What will the data gathered at NREL show if applied to this alternative procedure?
- Are labs accurately following the current NOCT procedure? Examination of test reports for 2 of the three modules showed deviations from 61215.

Conclusions and Continuing Work

- The IEC 61215 Procedure does not guarantee repeatable results
- 8 months of NREL data result in NOCT values ranging from 45.3 to 48.9C
- A Steady state heat transfer model supports that a 10C NOCT variation can result from changing sky, ground, and ambient temperatures
- 3 modules with previously reported NOCT values of 42.4C, 47.9C, and 52.3C show identical NOCT values in side-by-side testing
- Future work with include examination of suggested changes to the IEC procedure and gathering of data over continued months at NREL