Perovskite Research Lab Location Degradation

George Sutherland - 2024

Goal

Perovskite solar cells are a groundbreaking development in the world of solar energy. Although they have potential to provide a massive leap in solar technology, with their high potential efficiencies and tandem applications, they suffer from a quick rate of degradation from a number of intrinsic and extrinsic factors. The goal of this project is to determine one research facility of the five selected to set up a theoretical perovskite degradation testing site that will facilitate the lowest degradation over time in perovskite solar cells. The selected site will be the aggregate best performer in several metrics including low temperature, temperature fluctuation, relative humidity, UV light, and Oxygen, all known extrinsic degradation factors, thus fostering the lowest extrinsic degradation in the theoretical perovskite testing cells.

Data Collection

The research facilities used for the environmental data and to ultimately determine the ideal site were provided through the NREL website's laboratory API's. The research sites used were University of Florida, SOLRMAP University of Arizona (OASIS), University of Oregon (SRML), NREL Solar Radiation Research Laboratory (BMS), and Solar Technology Acceleration Center (SolarTAC). This data was collected from 01/01/2024 to 11/28/2024 and was stored in SQL Server. Data was processed and cleaned in SQL before analysis was performed to find and remove any irregularities. To confirm the importance of the extrinsic degradation factors on perovskite solar cells, research study data containing environmental test factors as well as time testing and final PCE loss were collected from The Perovskite Database website. Ultimately, conclusions between the PCE Loss/Hr testing metric calculated to determine relative degradation of the experimental cells and ambient extrinsic degradation factors could not be drawn in the dataset as several uncontrolled variables, namely the cell stack sequence itself, varied vastly between different experiments in the database. These intrinsic variables were too different with too few overall records between them to prove with any statistical significance that the extrinsic factors led to increased degradation. However, due to prior research and common field knowledge on perovskites, we can still make inferences as to which site, of the five, would lead to the lowest degradation of the cells based on the five environmental factors chosen.

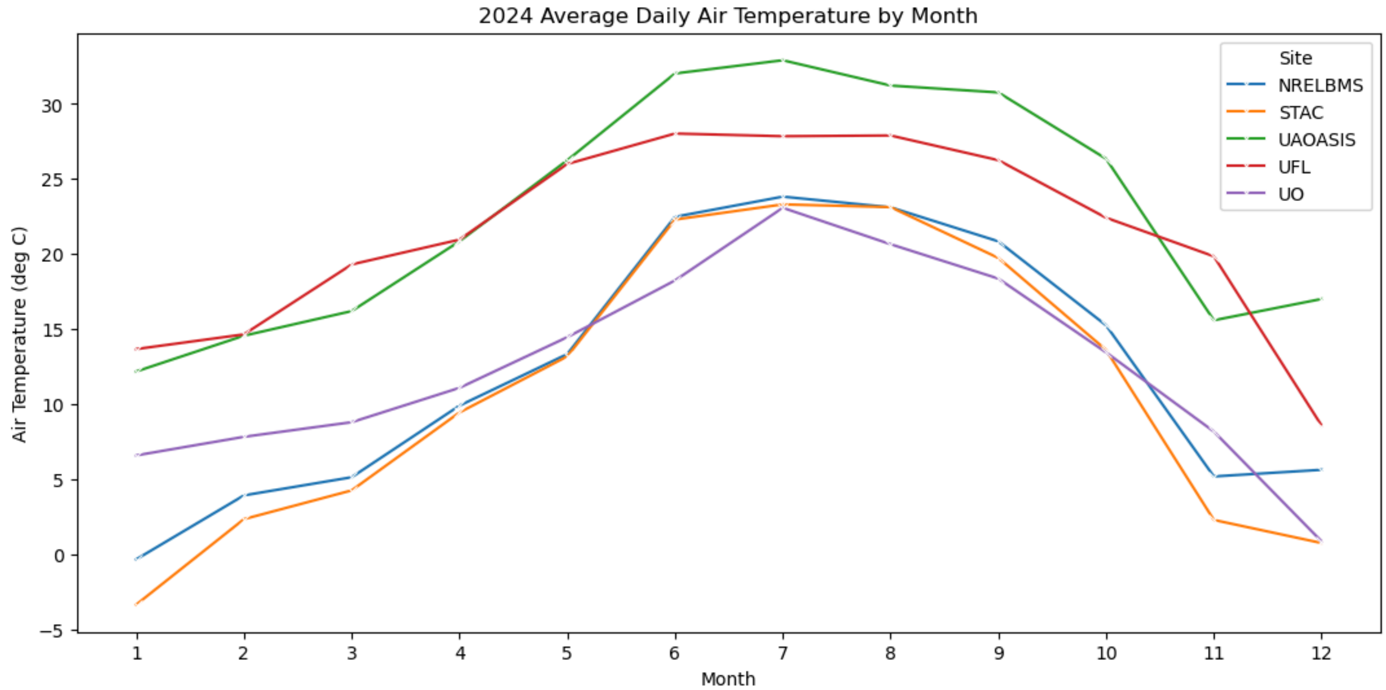
Results

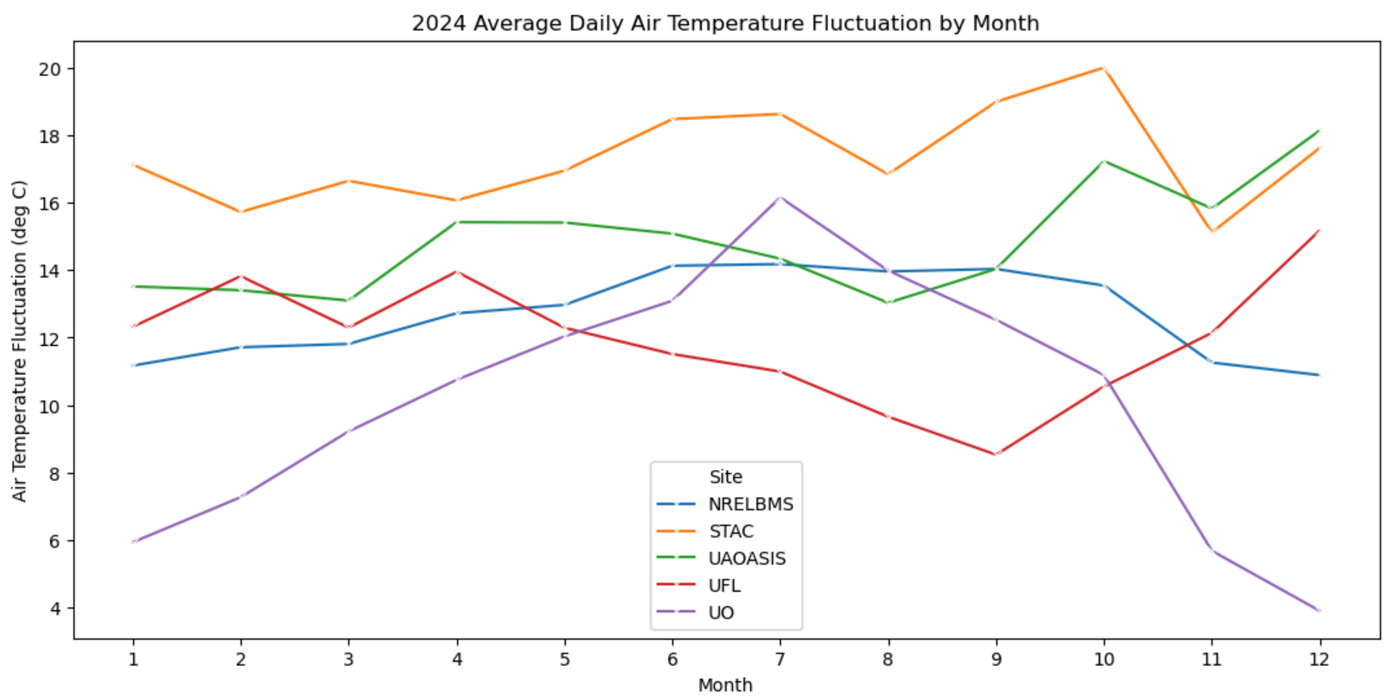
After comparison of the five different extrinsic factors of degradation collected from the research sites provided through the NREL: temperature, temperature fluctuation, relative humidity, UV light, and Oxygen all with an assumed equal weight, it can be said that the NREL Solar Radiation Research Laboratory (BMS) would be the site that would lead to the lowest degradation. In aggregate, this site had the lowest statistically significant combined rank when comparing the averages of their environmental factors.

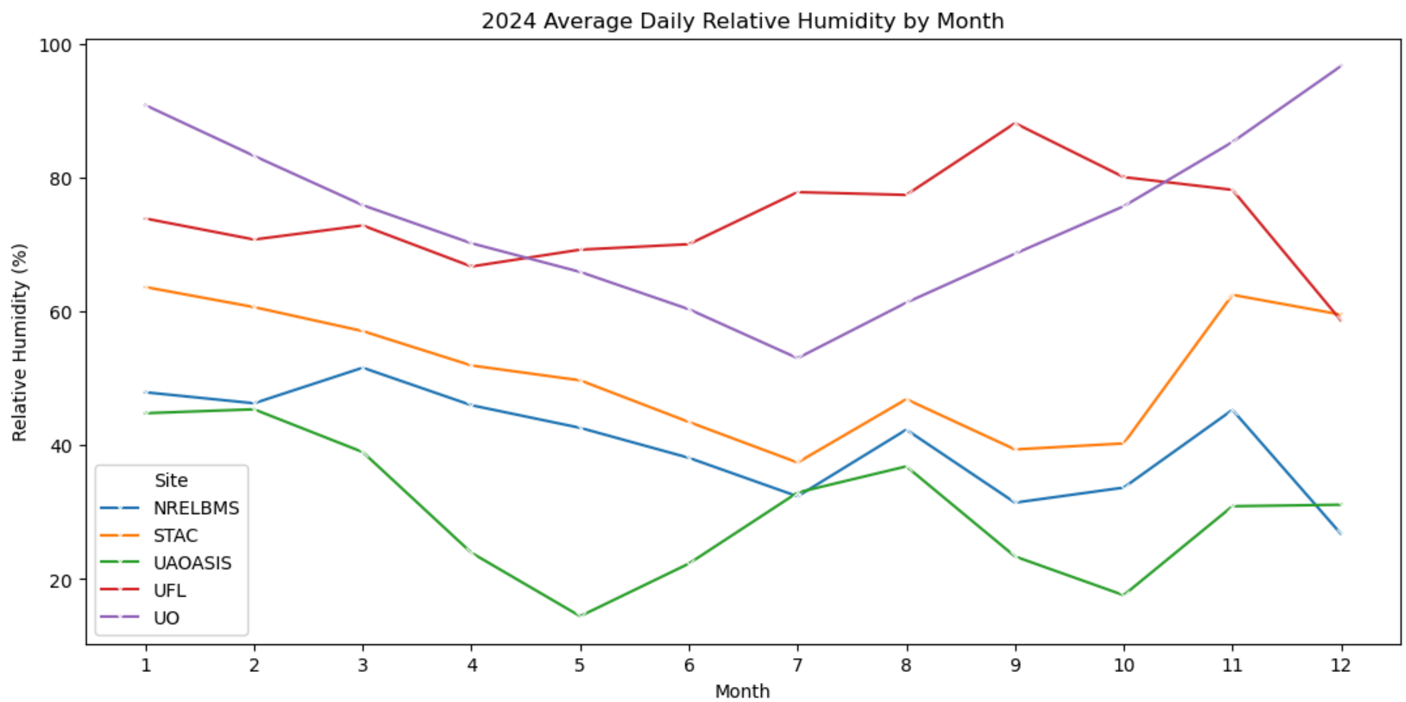
Detailed Results

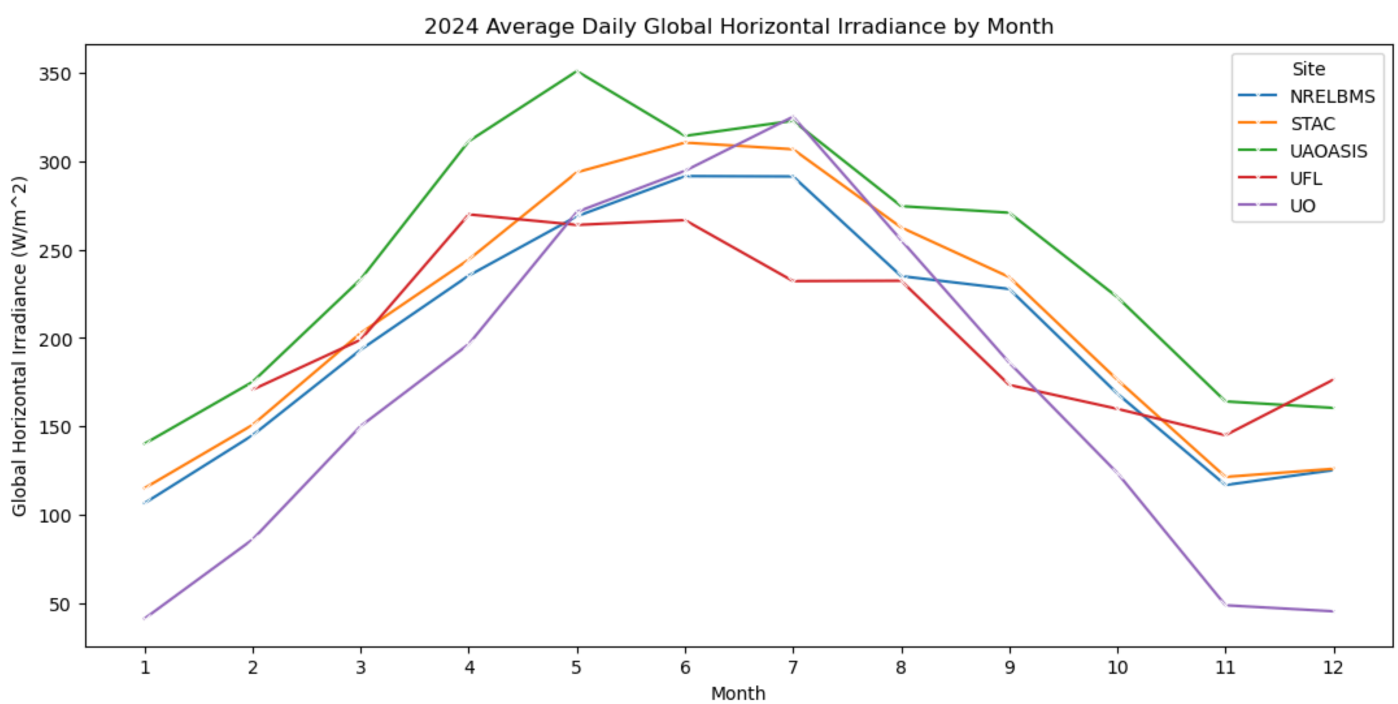
Although there exists robust research on the study of perovskite degradation, some of which was used and cited below, the analysis to determine the site where the lowest aggregate degradation would occur ideally would come with weighting assigned to the degradation factors used and collected through the NREL as well as statistical evidence of a relationship between these factors and efficiency loss in perovskite solar cells. To find evidence for this, data was pulled from the Perovskite Database, a database project that collects and validates perovskite research data and uploads it for the benefit of perovskite study. In this analysis, all data from the Perovskite Database was pulled from 01/01/2020 to 09/30/2024 that contained stability data tested at ISOS protocols. A total of 57 different tests were pulled and validated that contained power conversion efficiency (PCE) loss metrics as well as extrinsic stability test data including light intensity, relative humidity, and temperature. A new metric, PCE Loss/Hr was calculated in order to standardize the loss metric across the varied tests with different PCE loss as well as different durations of testing. Using only the tests with MAPbI perovskite compositions, a linear regression was performed on 80% of the data in the training set in order to determine which, if any, of the extrinsic factors had an effect on the dependent variable (PCE Loss/Hr). The model showed weak results with an r squared of 0.347 though it remained statistically significant. Looking at the independent variables, only the duration of exposure metric had a p value that was not well over 0.05, yet with a coefficient of -0.0001 we could also determine this was not a major determinant in PCE Loss/HR in our model. Looking at the variance inflation factor of our independent variables, we saw moderate collinearity, though not something that would have needed to be accounted for, and relatively normal distribution. When it was time to predict against the testing dataset (20%), an r squared of 0.6459 and a root mean squared error of 0.0378 was produced. Relative to PCE Loss/Hr, these results showed better than expected predictive results, however, when examining the residuals of the y predicted vs y test datasets, residuals well over 100% difference to the test dataset were produced, indicating that the model has inaccurate predictive abilities and combined with its weak ordinary least squares regression results and overall low sample size, we could not draw conclusions between the extrinsic factors in the test and PCE Loss/Hr. Fortunately due to preexisting field knowledge, temperature, temperature fluctuation, relative humidity, UV light, and Oxygen present in the air, are all known determinants in perovskite degradation. In this analysis they were used with an assumed equal weight in order to select the ideal site for minimal degradation. NREL API's were used to bring in data for the five research locations and were automated to insert into a SQL Server database. The data was cleaned prior to analysis by comparison to expected metrics, as well as checking the average, standard deviation, minimum, and maximum values for each day. Several records were removed, particularly from the University of Florida, though in the context of a year's worth of data it would not affect the overall average for each metric. Not all of the five sites had data for UV and Oxygen so to work around, they were replaced with global horizontal irradiance as well as station pressure. The analysis assumes that as irradiance increases, UV light will increase and as station pressure increases the Oxygen present in the air will also increase. Therefore these metrics indirectly get to our degradation factors. Using a multivariate analysis of variance, it was confirmed that the research sites, (or 'Source' in the test), are statistically significant in determining the variations in the extrinsic variables. The five variables were then ranked between the five sites based upon which site had the lowest value for each extrinsic degradation factor. In this analysis the lowest combined score in all five environmental factors would be the site that would lead to the lowest degradation. It was concluded that this would be NREL Solar Radiation Research Laboratory (BMS) due to it having the lowest combined daily average across all five in the year to date. After this was concluded, Tukey's range test was applied to each of the extrinsic factors to determine if the differences in daily averages were statistically significant. It was found that in both mean air temperature and mean global horizontal irradiance, the differences were found to be statistically insignificant between NREL BMS and SolarTAC, but even after removing these two variables out of the analysis, the site remained the leader in low degradation. NREL Solar Radiation Research Laboratory (BMS) would lead to the lowest degradation due to its location in Golden, CO. Although it wasn't the best performer in anything other than low Oxygen, due to its high altitude, it came in relatively low in air temperature, relative humidity, and global horizontal irradiance. The site outperformed SolarTac's metric performance handedly, despite both being located in Colorado due to SolarTac's location on the eastern plains where it is prone to higher temperature fluctuation, lower altitude, and increased UV exposure compared to its relatively mountainous counterpart.

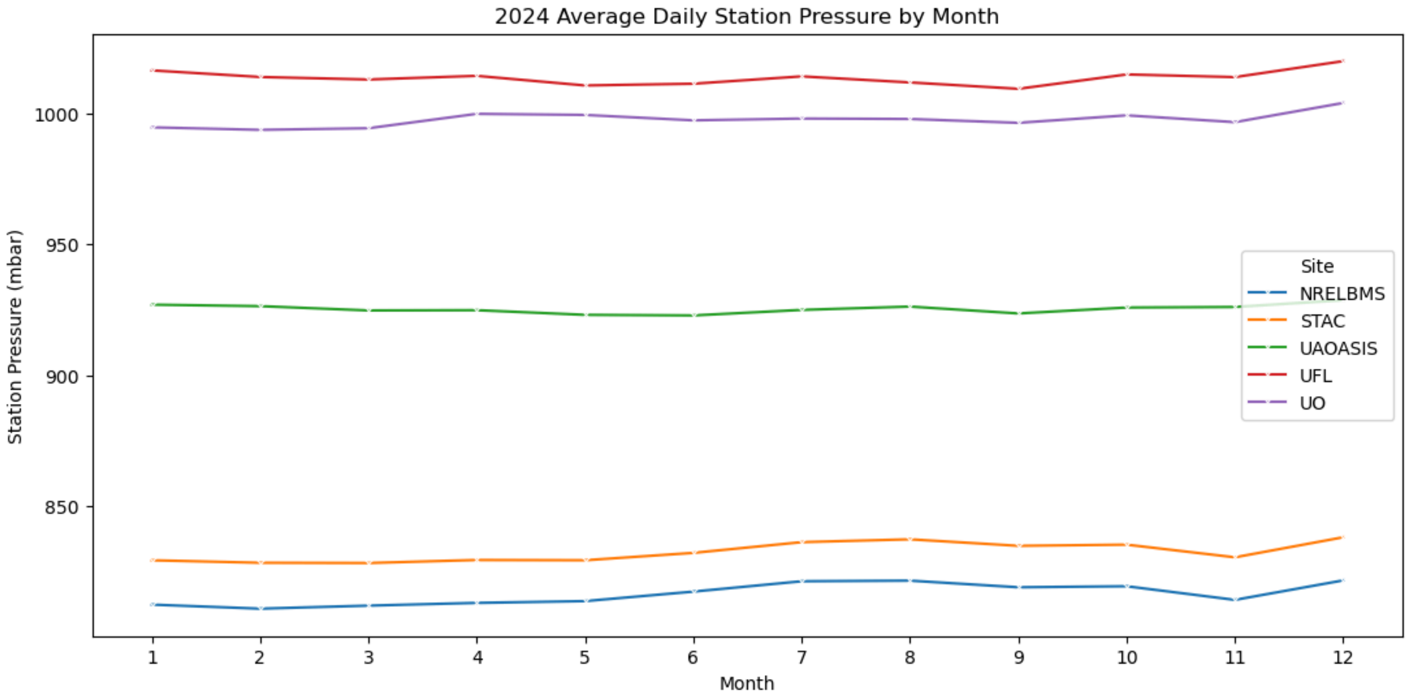
Visuals


2024 Average Daily Air Temperature by Month
Air Temperature (deg C)
Month
Site
NRELBMS
STAC
UAOASIS
UFL
UO
30
25
20
15
10
5
0
−5
1
2
3
4
5
6
7
8
9
10
11
12


2024 Average Daily Air Temperature Fluctuation by Month
Air Temperature Fluctuation (deg C)
Month
Site
NRELBMS
STAC
UAOASIS
UFL
UO
20
18
16
14
12
10
8
6
4
1
2
3
4
5
6
7
8
9
10
11
12


2024 Average Daily Relative Humidity by Month
Relative Humidity (%)
Month
Site
NRELBMS
STAC
UAOASIS
UFL
UO


2024 Average Daily Global Horizontal Irradiance by Month
Global Horizontal Irradiance (W/m^2)
Month
Site
NRELBMS
STAC
UAOASIS
UFL
UO



2024 Average Daily Station Pressure by Month
Station Pressure (mbar)
1000
950
900
850
1
2
3
4
5
6
7
8
9
10
11
12
Month
Site
NRELBMS
STAC
UAOASIS
UFL
UO

Site Extrinsic Metric Ranks

Source	AirTemperature(degC)	AirTemperature(degC)Rank
NRELBMS	12.95786004	2
STAC	11.81145856	1
UAOASIS	23.53752863	5
UO	13.65363237	3
UFL	22.41755308	4
Source	DailyTempFluctuation(degC)	DailyTempFluctuation(degC)Rank
NRELBMS	12.86621068	3
STAC	17.34102967	5
UAOASIS	14.60648961	4
UO	10.6621632	1
UFL	11.64974702	2
Source	RelHumidity(%)	RelHumidity(%)Rank
NRELBMS	41.5176422	2
STAC	50.26266571	3
UAOASIS	30.10248441	1
UO	71.91349652	4
UFL	74.9106034	5
Source	GlobalHoriz(W/m^2)	GlobalHoriz(W/m^2)Rank
NRELBMS	207.0332543	2
STAC	219.6668778	4
UAOASIS	252.5768722	5
UO	179.5897377	1
UFL	211.3331932	3
Source	StationPressure(mBar)	StationPressure(mBar)Rank
NRELBMS	815.9149845	1
STAC	831.9395907	2
UAOASIS	925.0833251	3
UO	997.1698021	4
UFL	1013.179011	5

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