SOLARONIX

Maintenance costs for solar simulators with various lighting technologies.

Based on Solaronix' exclusive light engine, our solar simulation equipment delivers a perfect and continuous artificial sunlight 24/7, allowing for accurate stability and performance assessments of solar cells at laboratory and industrial scale.

INNOVATIVE SOLUTIONS FOR SOLAR PROFESSIONALS

T A B L E   O F   C O N T E N T

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1. INTRODUCTION

This document presents the maintenance cost calculation for solar simulators using different lighting technologies. The analyzed technologies are plasma lamp, xenon lamp, metal halide lamp and LED lamp. This comparison is limited to solar simulators producing a “class A” spectrum according the norm IEC60904-9 related to the manufacturing of solar simulators for PV-market.

2. GENERALITIES

2.1 ABOUT THE SOLAR SIMULATOR

There to two ways to produce a solar simulating light in class A.

1. Using a lamp producing directly the “right” spectrum, as the plasma light engine does.
2. Using a lamp combined with an interference filter to obtain the “right” spectrum, as it is commonly the case with xenon and metal halide lamp.

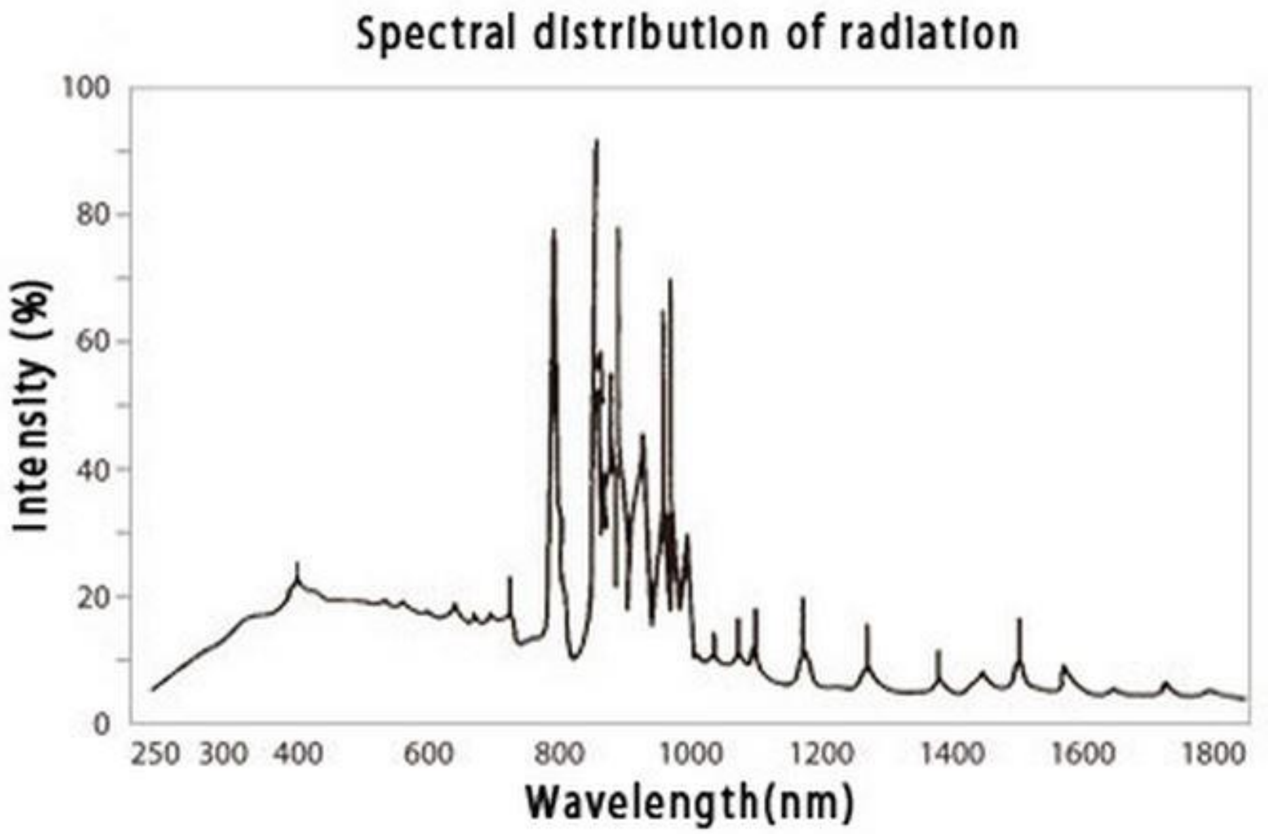
In the case 1, the maintenance costs are only the replacement of the bulb, or the exchange other light engine internal parts, which can be assimilated to a bulb replacement.

In the case 2, the maintenance costs are the replacement of the bulb and the renewal of the interference filter, which ages fairly quickly, as it is made from environmentally sensitive layers, i.e. thin-film coated structures on glass or polymeric substrates.

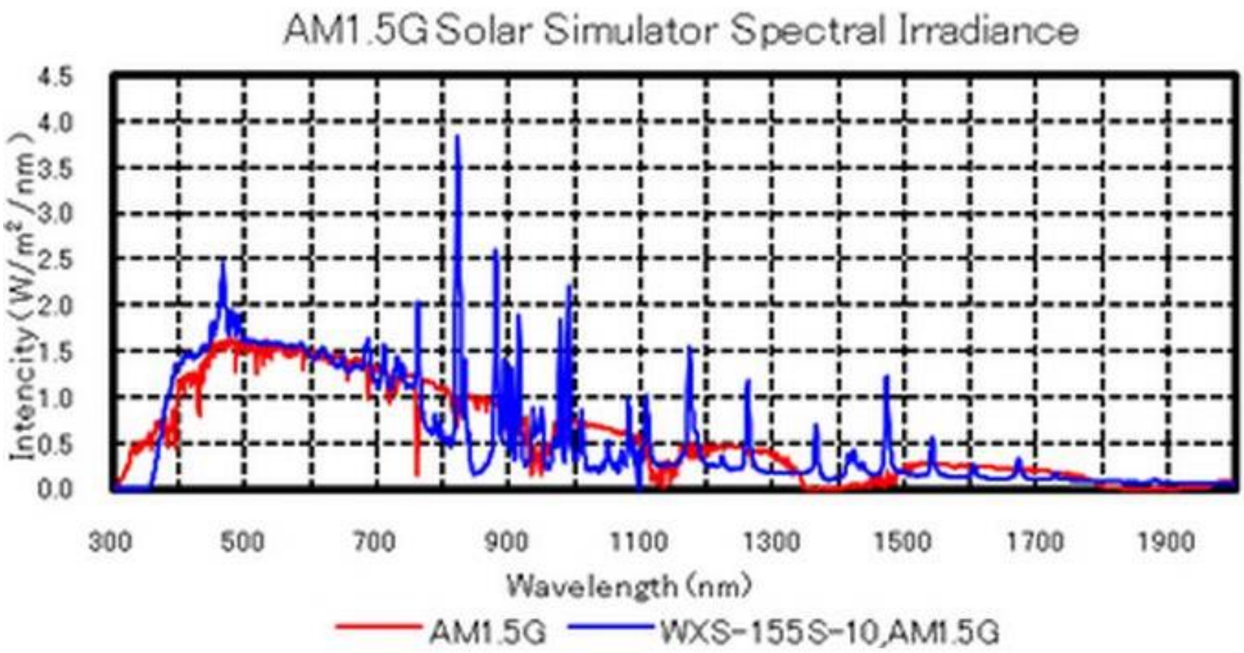
2.2 SPECTRAL MATCHING

2.2.1 Xenon

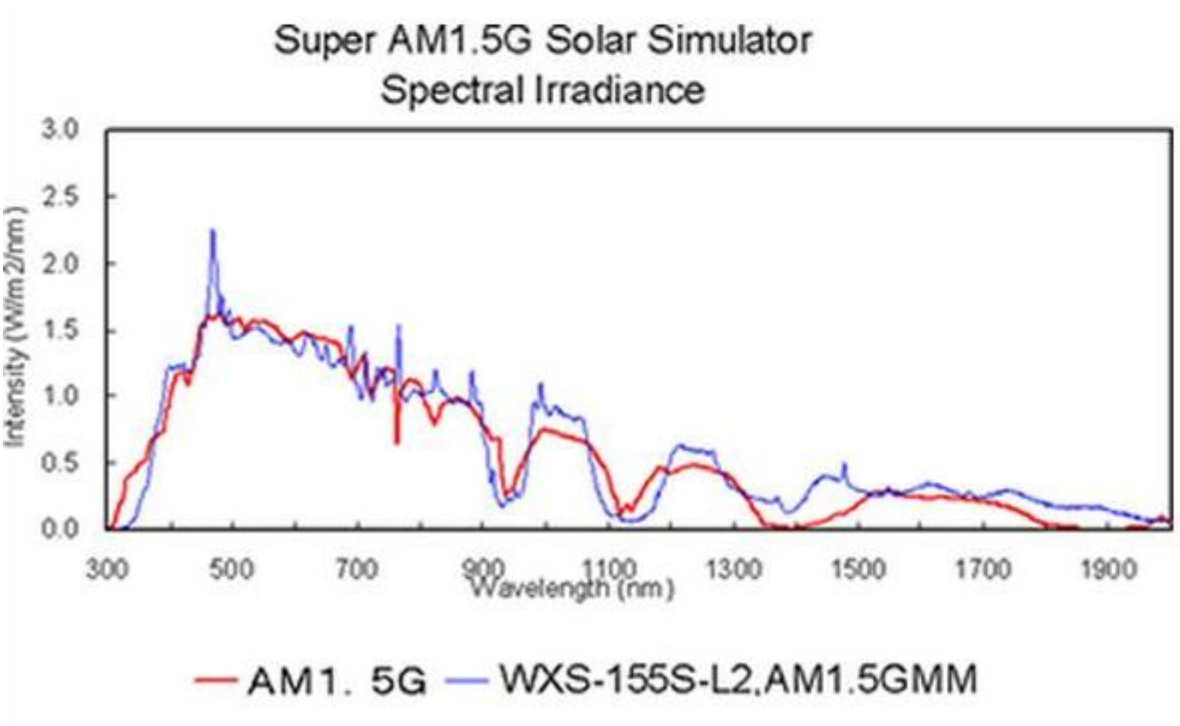
The xenon lamp produces the following spectrum.



Solar simulator without interference filter gives the following result. The matching is poor between 800 nm and 1100 nm.



To obtain a good matching with the sun spectrum, a xenon lamp based simulator should use an interference filter. This filter is an expensive part with a quite short lifetime.

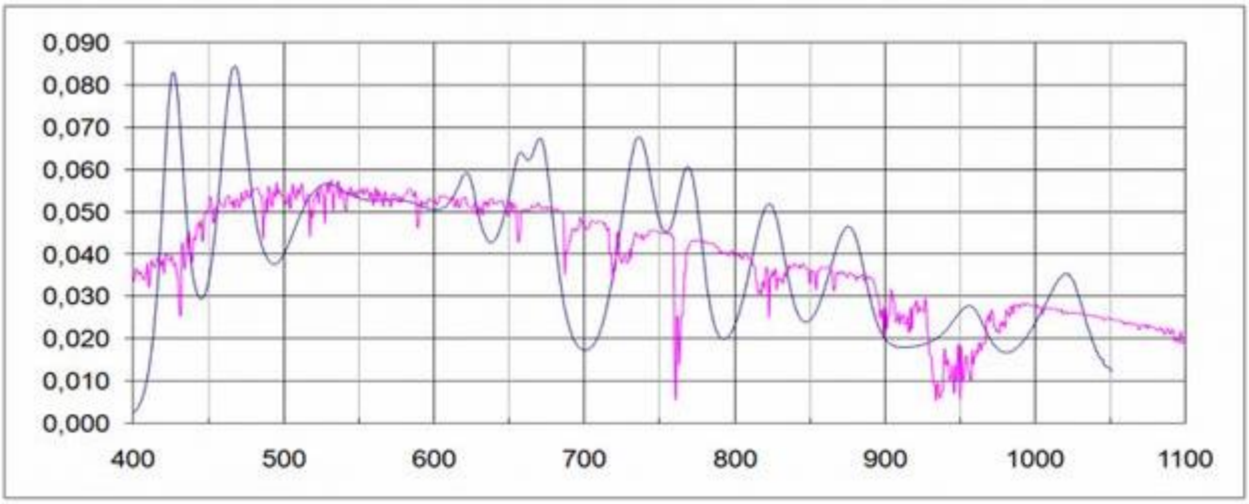


Source: http://www.wacom-ele.co.jp/

2.2.2 LED

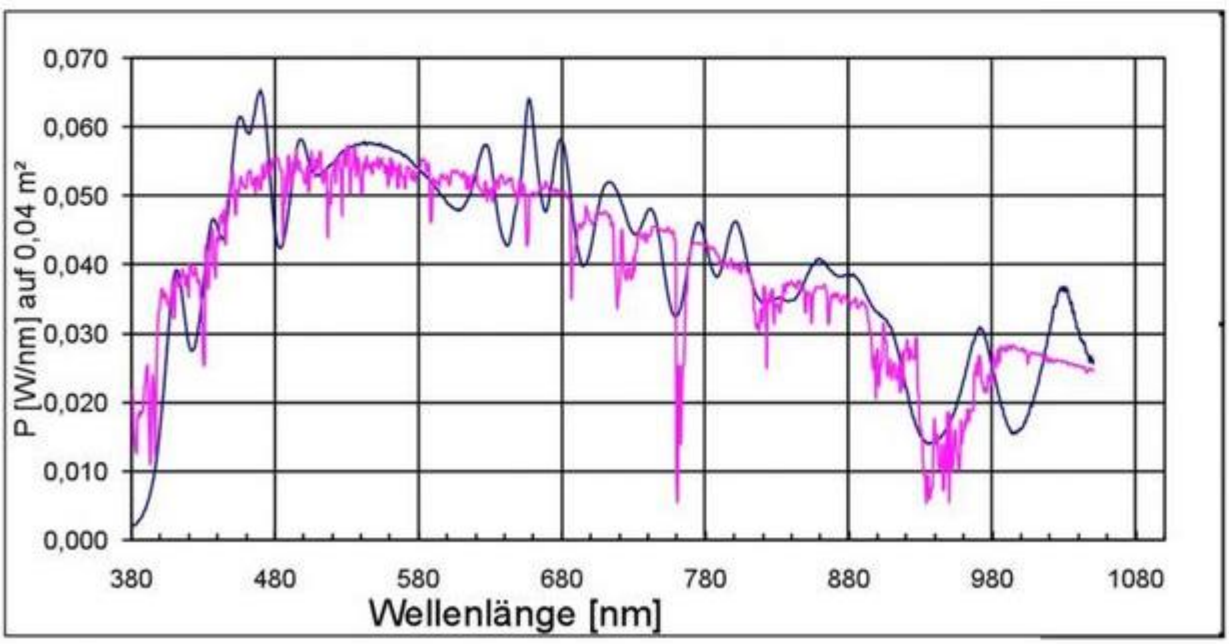
The LED gives a small spectral portion, and in order to compensate for the missing radiation portions within the spectral band, the power is increased to match the power percentage requested by the class A or A+ solar spectral band.
Many LED-solar simulators are rated in A+ spectrum, by matching a certain number of LED's within each spectral band (5-LED's at least).
Note: This type of simulators might not be well suited for thin-film & multi-junction PV devices, due to the missing radiation at certain portions of the spectrum.

2.2.2.1 Spectrum produced by 18 different LED's for sun simulator



The gap 400 nm to 500 nm has two overshoots to compensate for the "holes" in the LED-spectrum. The quality of this might be poor for certain types of PV-technologies. Despite that the global energy distribution within the spectrum is correct, or even in class A+.

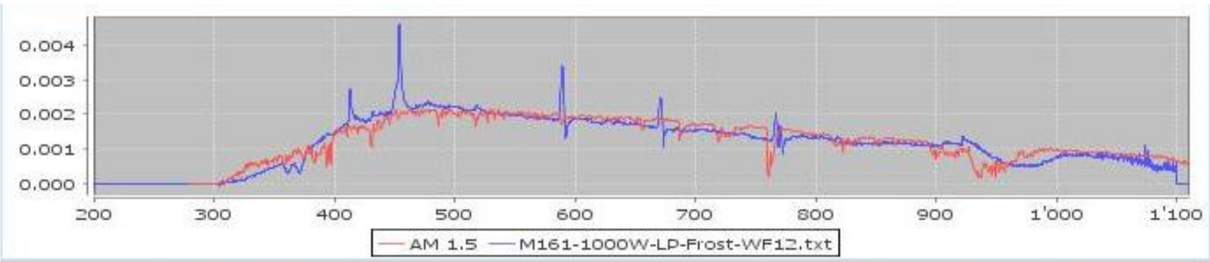
2.2.2.2 Spectrum produced by 26 different LED's for sun simulation.



In each band, the LED spectrum does not fit the real sun spectrum, but many peaks are compensating for the valleys in the spectrum.

Source : http://www.futureled.de/sunlike-spectrum.html

2.2.3 Plasma



IEC 609049	400-500 nm	500-600 nm	600-700 nm	700-800 nm	800-900 nm	900-1100 nm
AM 1.5 ratio	18.4%	19.91%	18.36%	14.92%	12.46%	15.94%
M161-1000W-L...	21.62%	20.16%	17.04%	14.06%	11.83%	15.29%
Mismatch	-17.51%	-1.24%	7.18%	5.77%	5.11%	4.1%

JIS C 8912	400-500 nm	500-600 nm	600-700 nm	700-800 nm	800-900 nm	900-1000 nm	1000-1100 nm
AM 1.5 ratio	18.4%	19.91%	18.36%	14.92%	12.46%	7.42%	8.52%
M161-1000W-L...	21.62%	20.16%	17.04%	14.06%	11.83%	8.29%	7%
Mismatch	-17.51%	-1.24%	7.18%	5.77%	5.11%	-11.66%	17.83%

JIS C 8933	350-400 nm	400-450 nm	450-500 nm	500-550 nm	550-600 nm	600-650 nm	650-700 nm	700-750 nm
AM 1.5 ratio	4.26%	8.14%	10.26%	10.07%	9.84%	9.49%	8.86%	7.92%
M161-1000W-L...	4.22%	9.6%	12.02%	10.43%	9.73%	8.91%	8.13%	7.4%
Mismatch	1.09%	-17.87%	-17.22%	-3.52%	1.09%	6.12%	8.31%	6.57%

Plasma lamp fits correctly the sun spectrum without large peaks, there are only small emission peaks within a continuous emission. The energy distribution produced by the lamp is very close to the real sun spectrum.

Plasma lamp produces a high fidelity energy distribution, thus a well suited solution to obtain high accuracy tests.

2.3 About lamp technologies

2.3.1 Spectrum stability

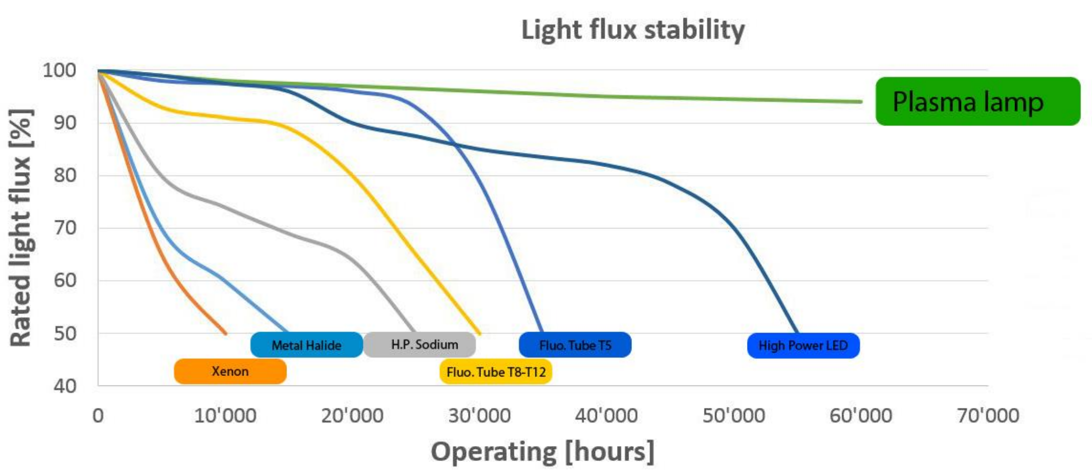
All lamp technologies using electrodes suffer from a spectrum shifting, as the electrodes are corroded during the long steady operation. The chemistry inside the electrical arc changes over time and thus modifies the spectrum. Moreover, most electrodes-based lamp technologies need an interference filter. This filter ages too over the time and introduces an additional spectral shift.

Plasma lamps are electrodeless devices, and the use of the interference filter is not required, as the bulb directly emits the right amount of light to simulate the sun's spectral radiation within a certain wavelength band. The chemistry inside the electrical discharge is stable over long time, so this kind of light source technology does not lead to a spectrum shifting.

2.3.2 Light flux stability

All lamp technologies experience a light flux reduction over time.

For a solar simulator, it is important that the light flux is stable. If the light flux is not stable, it is difficult to know if the sample ages or the lamp is degrading over time.



The Plasma lamp seems to be the best technological choice for obtaining a stable light flux, no tracking of the lamp aging is required.

Note: The observed degradation is negligible at the bulb level, so the only noticeable decay is from the surrounding optical materials, like reflectors or diffusers that are close to the light source.

3. MAINTENANCE COST

3.1 ASSUMPTIONS

3.1.1 General framework

In this calculation we take care of some critical parameter for the solar simulation:

1. The light flux degradation over the time.
2. The spectrum shifting.

To compensate for the light flux dropping, the power of the light engine must be increased over time. In this case, a calibration of the solar simulator is required periodically thus adding costs.

To compensate the spectrum shifting, the lamp bulb must be changed often. To define if the lamp must be changed, a calibration of the solar simulators also required. This calibration has also a cost to be taken into the account.

3.1.2 Life time

3.1.2.1 Lamps

Lighting Technology	**Life time [hours]**
Xenon	1’000
Metal Halide	1’000
LED	20’000
Plasma	40’000

3.1.2.2 Interference filter

Filter technology	**Life time [hours]**
Interference layers filter	10’000

3.1.3 Light source cost

Lighting Technology	**Cost [USD]**
Xenon	1’500
Metal Halide	1’500
LED	2’500
Plasma	6’500

3.1.4 Cost of bulb replacement

Lighting Technology	**Cost [USD]**
Xenon	400
Metal Halide	300
LED	2’500
Plasma	100

At the end of the lifetime described at the paragraph 3.1.2.1, the bulb is changed, taking into account the costs indicated in the table above.

3.1.5 Cost of interference filter replacement

Filter	Cost [USD]
Interferential filter	5'000

At the end of the lifetime described at the paragraph 3.1.2.2, the filter is changed, taking into account the costs indicated in the table above.

Some solar simulators are equipped with various interference filters, so the cost of replacement is probably higher than the ones expected in our calculation.

3.1.6 Efficiency of light sources based on different lamp technologies

The efficiencies of lighting devices are given in lumen per watt.

The lumen is a power flux unit defined between 400nm and 780nm, that takes into account the sensitivity of the human eye, and the energy outside this range is not recorded. But for the sun simulation, the useful range is between 300 and 2500nm, so the lumen per watt efficiency is only of minor interest.

The important feature is that the energy distribution must be similar to the sun's radiation distribution, and the light flux efficiency must be calculated in watt per watt.

Commonly, all lighting technologies are qualified for their efficiency in lumen per watt. For this reason, we choose to use this unit in first approximation.

Lighting technology	Efficiency [lm/W]
Xenon	40
Metal Halide	68
LED	100
Plasma	70

Source: http://en.wikipedia.org/wiki/Luminous_efficacy

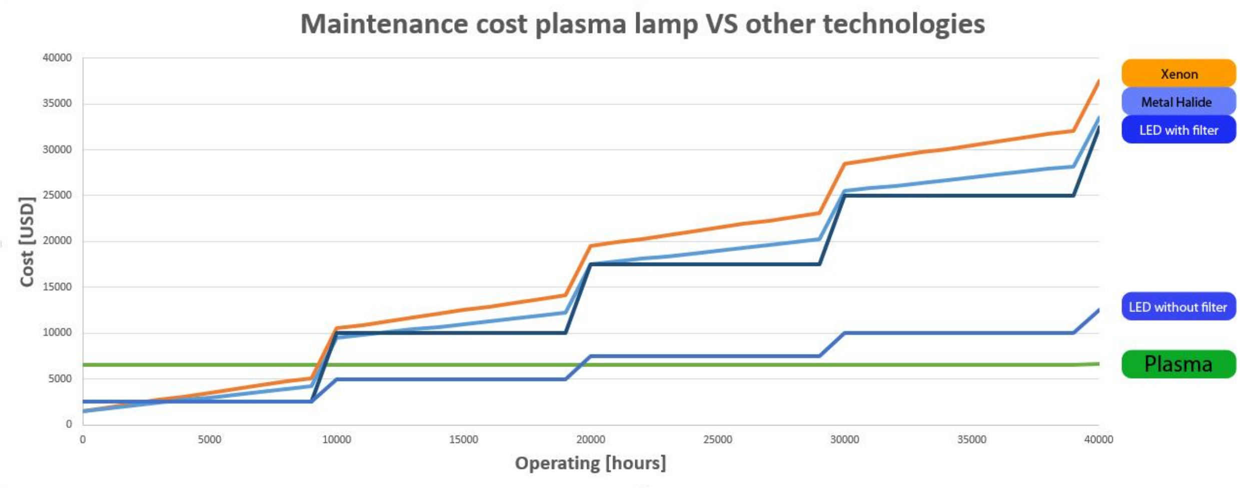
The lighting efficiency has an influence on the number of light source required for a given illuminated area, and it also has an incidence on the electricity consumption.

3.2 RESULTS

3.2.1 Maintenance cost

This table indicates the calculated maintenance cost after 40'000 hours of operation to illuminate a surface of 0.25 m^2 at 1000W/m^2 with a spectrum in class A. (Ex. 50 x 50 cm area)

Lighting technology	Cost [USD]
Xenon	37'500
Metal halide	33'500
LED with filter	27'500
LED without filter	12'500
Plasma	6'600

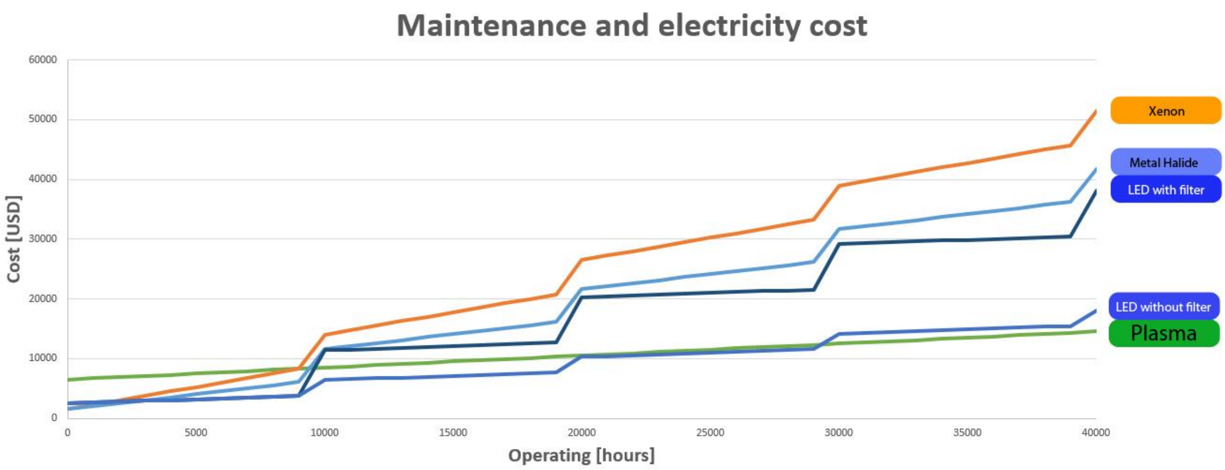


3.2.2 Maintenance and electricity costs

This table indicates the calculated maintenance and electricity costs after 40'000 hours of operation to illuminate a surface of 0.25 m^2 at 1000W/m^2 with a spectrum in class A.

The electricity cost is estimated at 0.2 USD per kWh in our calculation.

Lighting technology	Cost [USD]
Xenon	51'500
Metal halide	41'735
LED with filter	38'100
LED without filter	18'100
Plasma	14'600



4. CONCLUSION

Xenon lamp with interference filter gives good result for the spectral matching, but the maintenance cost is very high. Plasma lamp saves an estimated 39'900 USD after 40'000 hour of operation for a similar test result.

Metal halide lamp with inference filter gives a good result of the spectral matching, but the maintenance cost is also significant. Plasma lamp saves an estimated 27'135 USD after 40'000 hours of operation for a similar test result.

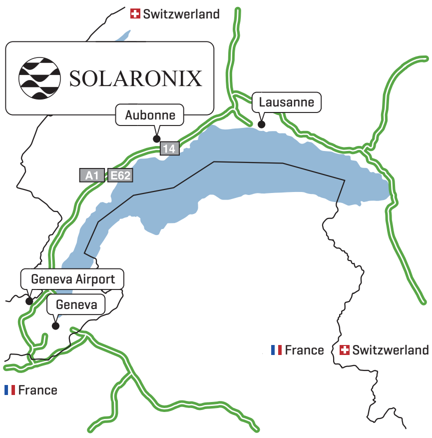
LED with interference filter gives a good result of the spectral matching, but the maintenance cost is still important. Plasma lamp saves an estimated 23'500 USD after 40'000 hours of operation for a similar test result.

LED without inference filter gives a poor result of spectral matching, but the maintenance cost is less expensive. Plasma lamp saves only an estimated 3'500 USD after 40'000 hours of operation. The result is not at the level of a high fidelity testing, as the spectral matching over all wavelengths is to poor compared with the other technologies.

This table indicates the cost saved when using a plasma lamp after 40'000 of operating to illuminate 0.25 m^2 at 1000W/m^2 with a spectrum in class A.

Lighting technology	Cost saved with plasma lamp [USD]	Percentage
Xenon	36'900	253%
Metal halide	27'135	186%
LED with filter	23'500	161%
LED without filter	3'500	24%

Plasma lighting technology is thus an economically interesting choice for solar simulation, and it brings a low maintenance cost solution to the user of solar radiation simulating devices.



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