Utrecht University

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Shining Light on Limits: Luminescent Solar Concentrators as Transparent Photovoltaic Windows

In densely populated areas where horizontal surfaces are scarce, the luminescent solar concentrator (LSC) can function as a photovoltaic window. This enables localized electricity production in the built environment. However, to function as a window, sufficient visible light transmission is required, a trade-off with electricity production. This paper shines a light on the maximum possible efficiency of an LSC that still transmits sufficient visible light.

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Working principle of a luminescent solar concentrator, irradiance (1) from the sun is incident on the transparent slab (waveguide) and absorbed by the luminophores (grey spheres) to be subsequently emitted (2), and part of this will arrive at the sides via total internal reflection (3). Loss mechanisms include escape cone losses (4), quantum yield (the ratio of the emitted photons and the absorbed photons by the luminophore) losses (5), reabsorption by the luminophore (6), and absorption by the waveguide (7). The light which is not absorbed is transmitted (8).

Higher concentration of particles > more absorption > less transmission but more electricity generation. Find the sweet spot of transmission vs power, i.e., the optimal point!

Transmission vs power:

Examples of Average Visible Transmission (AVT/VLT) an **AVT > 55%** is required for a functioning window.

Example of color rendering index (CRI). For window applications, a **CRI > 70** is considered appropriate.

PCE (power conversion efficiency):

$$\eta = \frac{Electrical\ power}{Irradiance}$$

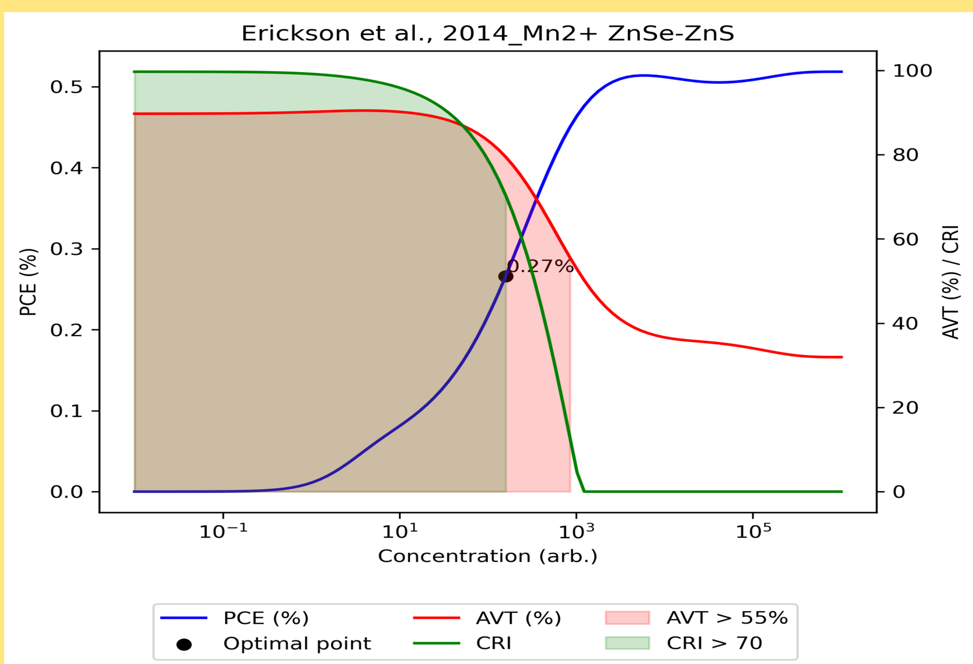
Maximize: PCE

Methods:

- Exhaustive literature research found 30 LSC review articles.
- Based on the aggregated review, data from 74 luminophores is found.
- Relevant particle data is extracted and used in our algorithm [1].
- The algorithm supports tandem and two luminophores in one LSC.
- Find the optimal point for all luminophores and configurations.

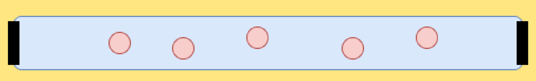
Input parameters:

- PMMA waveguide (30x30x0.5 cm^3)
- Silicon solar cell (20% STC efficiency)



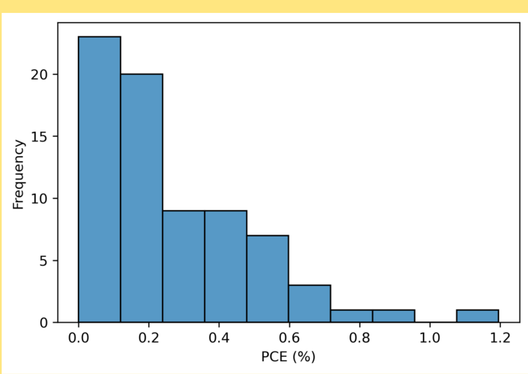
The relationship between PCE, AVT, and CRI for Mn^{2+} ZnSe/ZnS luminophore as found by the numerical algorithm. The optimal point has a PCE of 0,27%.

Results:

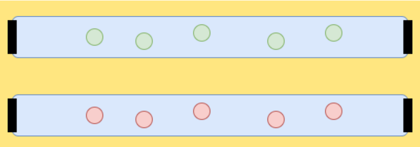


Single configuration: one LSC one luminophore

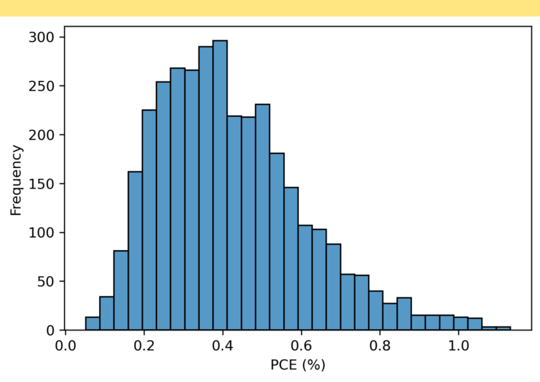
Optimal PCE values for all 74 tested luminophores-based constraints: AVT >55% and CRI >70.



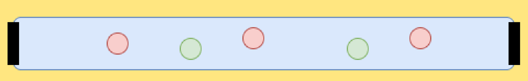
Tandem configuration: two LSCs two luminophores



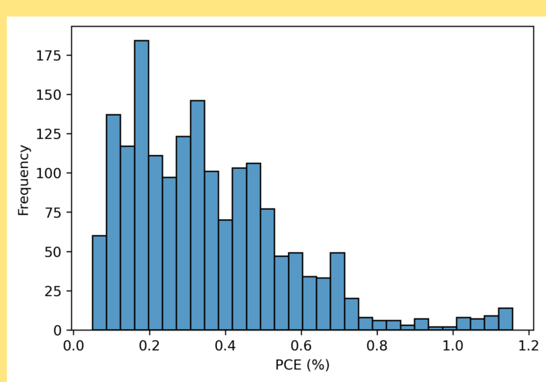
Optimal PCE values for all 74*73 tested tandem luminophore configurations with constraints: PCE >0.05% AVT >55% and CRI >70. After applying these constraints, 3465 variations were left



Two-in-one: one LSC with two luminophores



Optimal PCE values for all 74*73/2 tested two luminophore combinations in one LSC with constraints: PCE >0.05% AVT >55% and CRI >70. After applying these constraints, 1736 variations were left.



Conclusion:

Based on known luminophores and with a size of 30x30x0,5 cm^3 and a PMMA waveguide, a single, tandem, or two-in-one LSC can produce, in ideal cases, around 1 W/m^2 with an AVT > 55% and a CRI > 70.

[1] De Bruin, T. A., & Van Sark, W. G. (2023). Numerical method for calculation of power conversion efficiency and Colorimetrics of rectangular luminescent solar concentrators. *Solar RRL, 7*(5). https://doi.org/10.1002/solr.202370054

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