Evaluation of cooling requirements for thermophotovoltaic devices

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Thermophotovoltaic (TPV) devices generate electrical power under the illumination of a body at high temperature (>1000 °C) [1, 2]. The radiation power density incident on the TPV cell can be compared to that in concentrated solar photovoltaics (CPV). For example, when the emitter is a blackbody at 1200°C, the TPV cell receives 26.7 W·cm^{-2}, corresponding to a solar concentration factor of 267. High-illumination conditions raise the question of how much heat must be dissipated to operate the TPV cells near room temperature. A recent review of the main performance metrics of TPV devices tested in laboratory conditions [3] suggests that cooling requirements necessitate careful investigation.

By using a 1D detailed balance approach and a simple thermal model involving an effective heat transfer coefficient (h_{eff}) and the temperature (T_{cold}) of the heat sink to which heat generated in the TPV cell (Figure 1) can be dissipated, it is possible to get insights into the cooling requirements for TPV devices. Supported by curves showing pairwise efficiency as a function of electrical power density (e.g., Figure 2), our findings suggest that operating the TPV cell near room temperature requires a cooling system with a significantly high effective heat transfer coefficient (about $10^3 - 10^4$ W·m^{-2}·K^{-1}). The cooling challenge worsens when the cell bandgap decreases, because of the combination of increasing electrical power density and decreasing pairwise efficiency. The cooling demands grow with the emitter's temperature and the view factor. However, they can be mitigated by diminishing both in-band and out-of-band transmission functions. The optimization of bandgap for pair efficiency or power density is inadequately predicted when the cell is presumed to function in the radiative limit (Figure 2).

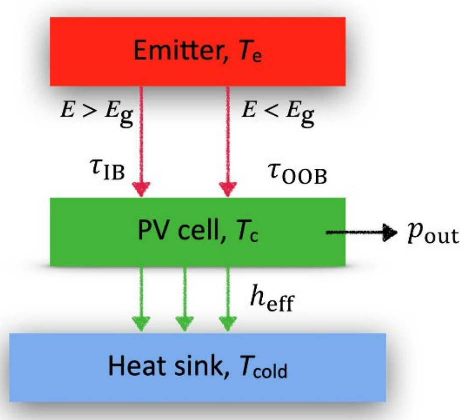

Figure 1: Schematic of a generic TPV device composed of an emitter, a PV cell, and a cooling system to dissipate the heat generated in the cell (from [4]).

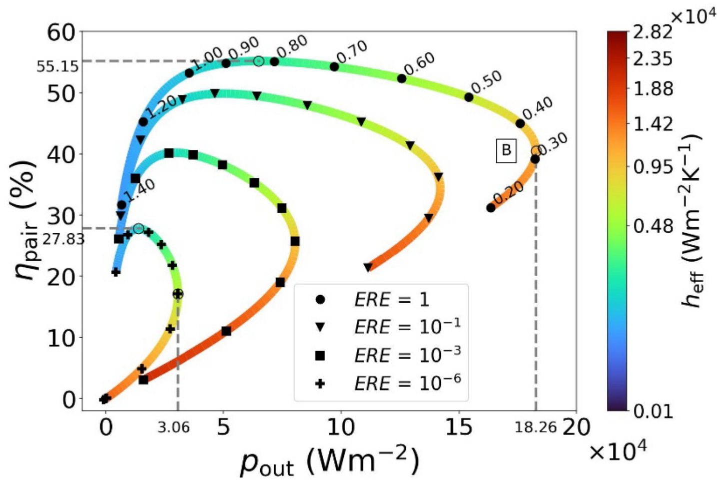

Figure 2: Pairwise efficiency vs power density for four values of the External Radiative Efficiency (*ERE*). Each curve shows the effective heat transfer coefficient (h_{eff}) required to maintain the PV cell at 50°C, as a function of its bandgap, assuming an emitter temperature of 1500°C, a cold sink at 25°C, a view factor of 1, and in-band and out-of-band transmission values of 1 and 0.02, respectively (from [4]).

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[3] B. Roux, C. Lucchesi, J.-P. Perez, P.-O. Chapuis, and R. Vaillon, Journal of Photonics for Energy 14 (4), 2024.
[4] B.R. Mishra, A. Vossier, I. Revol, G. Almuneau and R Vaillon, article under review, 2025.

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