Applicable subject number: 6.1 PV on/in Buildings, Infrastructure, Landscape, Water and Nature

On Module Temperature in Floating PV Systems

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Floating PV is one of the emerging trends in photovoltaics (PV). Especially countries in Southeast Asia with available water areas have started to adopt this concept increasingly, particularly for locations were land availability is a concern. As with many new concepts, there are claims about the benefits of floating PV that are, as yet, not well substantiated by supporting data. Among the advantages of floating PV, frequently the “cooling effect of water” is mentioned, but is typically not specified further. In this study, we show that the mere presence of water is not a determining factor in the temperature of floating PV installations. In our analysis, we consider a floating PV installation and a rooftop PV installation on the same site in Cambodia. For this site, we find that the daytime temperatures of the floating installation are significantly higher than those of the rooftop installation, with temperatures differences at noon frequently exceeding 10 K. At nighttime, we find that both systems exhibit similar temperatures and can be assumed to be in thermal equilibrium with the ambient air. The temperatures of the water body on which the floating installation sits, on the other hand, are above ambient during the night and below during the day. When modelling the temperatures of these PV installations we find that the water temperature has no discernable impact on the temperature of the floating PV installation, and that the differences in temperature between the two installations are best explained by a reduced wind cooling of the floating PV installation.

There are further notable differences between the two configurations. Apart from a higher daily operating temperature, the floating PV installation also exhibits a smaller thermal inertia. The floating installation reaches ambient temperatures at night faster than its counterpart on the roof does. When fitting with our model, we find a smoothing constant of 35 minutes for the rooftop system and one of 7 minutes for the floating installation. The rooftop system appears to be in good thermal contact with the roof itself; the two also show very similar temperatures. The floating system mostly appears to be in thermal contact with the ambient air. We also note a very small difference in the Ross coefficient that results in the best fit for each system. This is plausible, although the difference is not statistically significant.

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The site:

We present our observations on the temperature of two PV installations located in Cambodia (~100 km south of Phnom Penh). The two sites are located within meters from each other, with one installation floating on a water reservoir and the other covering the roof of a nearby building. An image of the installations, as well as a list of measured parameters are shown in Figure 1.

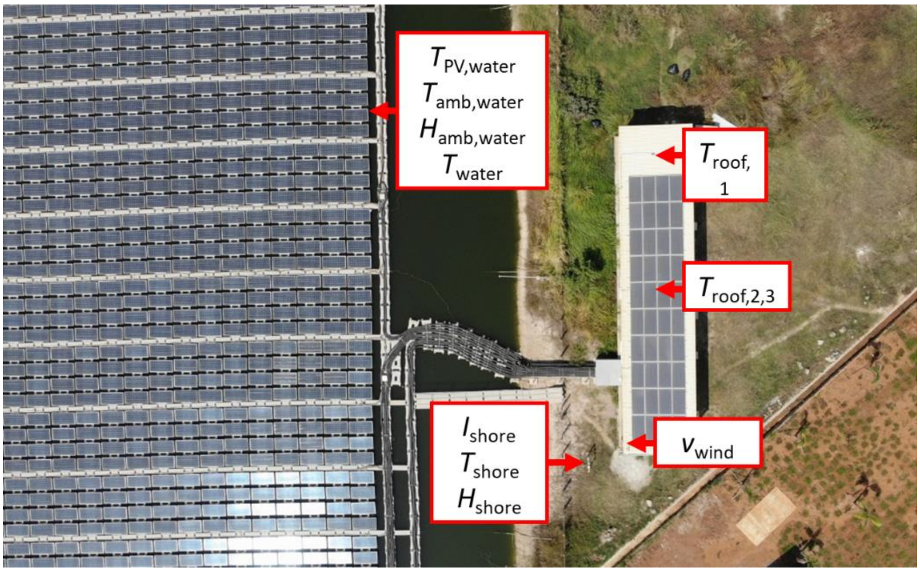

Figure 1: *Aerial image of the site with the two PV installations. Also included are the location and functions of the different sensors that produced the data used in this work.*

The sites are equipped with multiple sensors, measuring insolation, temperature, humidity, wind speed, wind direction and the output of the PV plant at several locations. For the presented analysis a subset of these measured parameters was used. Specifically: The temperature of the floating PV installation ($T_{PV,water}$), measured at the rear side of a floating module; the temperature of the modules on the rooftop ($T_{PV,roof}$), measured at the rear side of a module; the water temperature (T_{water}), measured at a depth of 0.3m in the reservoir, and the ambient temperature ($T_{ambient}$), measured close to the shore of the reservoir. Insolation was measured on several stations with differences that are insignificant for this study, hence only the value of one sensor close to the shore (I_{shore}) was used. Humidity was measured directly at the two installations (H_{water} and H_{roof}). Wind speed and direction were measured with a single sensor on top of the roof where panels are installed (v_{wind}). Measurements commenced in early-October 2019. Results shown in this abstract use data measured over a period of 80 days. By the time of the conference, more than 8 months' worth of data will be available.

Observations:

Figure 2a shows the median temperature for each timestamp for both PV installations. Contrary to expectations, we observe that the floating PV system during the day is significantly hotter than the installation on the rooftop. The median temperature difference in the three hours around noon is 8.1K. Also shown in the figure are the median water- and ambient temperature. An indication about which factor determines the thermal equilibrium of the PV systems can be obtained when looking only at the night-time temperatures (Figure 2b). First, we observe a small difference between the temperatures of the two PV systems; the floating PV system is indeed at a lower temperature at night (1.2K). An possible explanation for this difference is radiative cooling [1]; the floating system exhibits this, whereas the rooftop PV system is thermally coupled to the roof itself (no shown), which is why this cooling mechanism is missing. It should be noted, though, that sensor uncertainties are in a similar range (± 1K). We also observe that the water temperature of the reservoir at night is about 3K above ambient. We so far see no sign that the water temperature has any impact on the temperature of the floating PV system.

a) median temperature b) night temperature

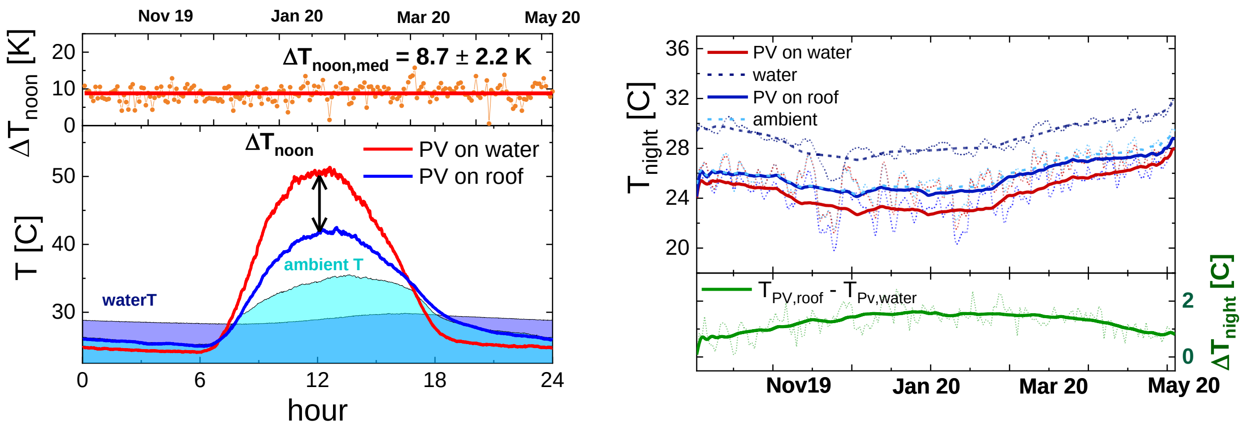

Figure 2: *a) median temperature for each timestamp of the floating PV installation (red line), the rooftop installation (blue line), the ambient (cyan) and the water (blue). b) nighttime temperatures for the two PV systems (red and blue), ambient (black dots) and water (grey dots).*

Modelling results:

Modelling results using the module temperature model described in [2] are shown in Figure 3a for the rooftop system and Figure 3b for the floating system. The model generally describes module temperatures with high precision, but does not capture rare events of high module temperature very well. When modelling the floating system, temperatures are underestimated unless wind cooling is reduced. The best fit is obtained when wind cooling is reduced to 20% of its original value, while keeping all other parameters at he same level as for the rooftop system.

However, also when fitting the floating system independently, reduced wind cooling needs to be assumed to fit the available data.

a) rooftop installation

b) floating installation

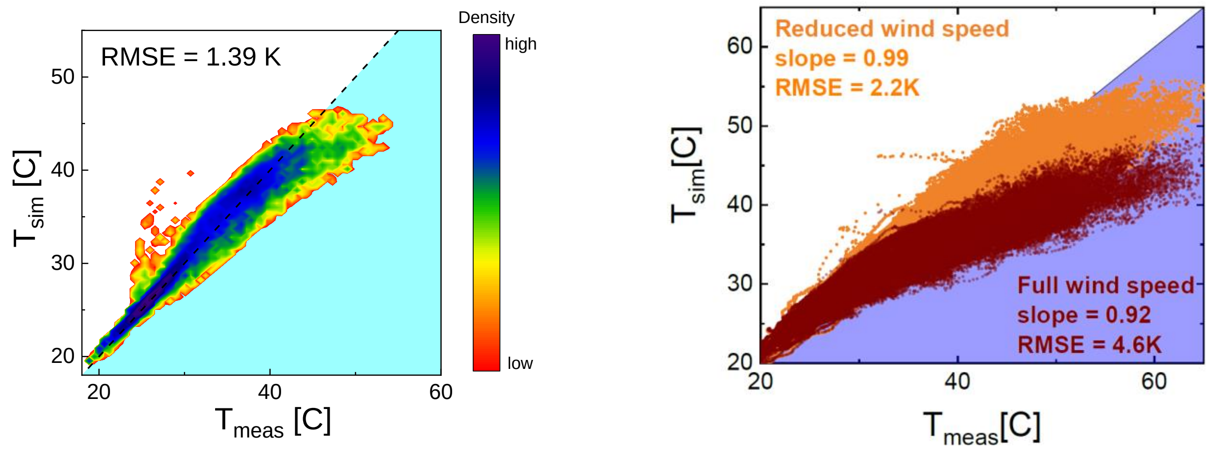

Figure 3: *a) Comparison between simulated and measured module temperatures. The plot shows the density of points with red colors indicating rare events and blue colors indicating frequent events. Comparison of simulated and measured temperatures of the floating PV system (b). The simulation assuming full wind speed is shown in brown, the one assuming a reduced wind speed in orange. The best agreement was achieved assuming wind speed was reduced to 20% of its original value.*

Final words:

Generally, our findings show once more that one should be weary of generalizations. Just because a PV system is floating does not mean it is necessarily better cooled. We find that the main determining factors for the module temperature are the ambient temperature, insolation and exposure to wind. Water bodies may affect these parameters, depending on their size and location, and hence may influence PV installations indirectly. We find no indication, however, that there is a direct heat exchange between panels and water. Direct thermal contact with water is possible, but requires additional measures (see, for example [3]). As shown in this study for the example of a comparably small water body, constructing a floating PV installation may not offer any thermal advantages at all – in our case most likely the lower altitude of the panels reduces exposure to and cooling from wind. This results in a higher temperature compared to a nearby system on a roof.

Bibliography:

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