# Irradiance and Temperature Uniformity on Vehicle Roof

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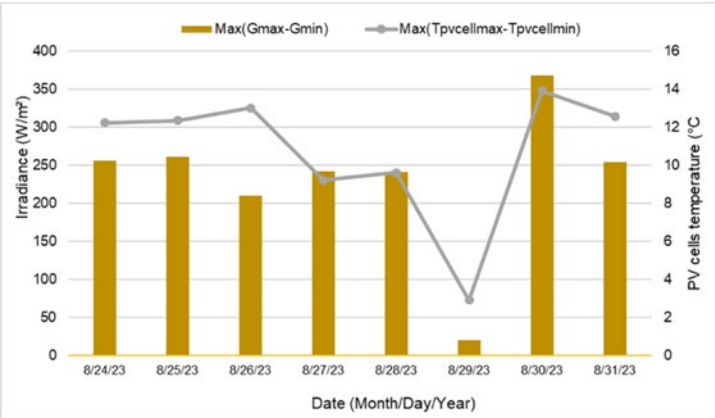
## Executive Summary

In the transport sector, battery and plug-in hybrid electric vehicles are being adopted globally as a solution to mitigate CO2 emissions. In line with this, vehicle emissions targets have been proposed and adopted by many countries and policy bodies around the world with goals for the adoption and use of electric vehicles in the near future. With widespread electrification of transportation, PV generated electricity and other renewable energy sources are needed to leverage the EV adoption into even more significant CO2 emissions reductions. The distributed nature of PV electricity generation offers new opportunities for charging battery electric vehicles.

Options for low-carbon charging of electric vehicles include charging from the existing grid network with PV or other sustainable electricity sources, charging from a dedicated charge point with local PV electricity generation, or directly and independently with on-board PV (PV-powered vehicle). In order to contribute to reducing the CO2 emissions of the transport sector and to enhance PV market expansions, IEA PVPS Task 17 is aiming to clarify the potential of the utilization of PV in transport and to propose how to proceed towards realising the concepts. Task 17's scope includes various PV-powered vehicles such as passenger vehicles, light commercial vehicles, heavy duty vehicles and other vehicles, as well as PV applications for electric systems and infrastructures, such as charging infrastructure with PV, battery and other power management systems.

Among these options, this report has focused on PV-powered vehicles, with on-board integrated PV systems (VIPV). A VIPV system can be described as a combination between a PV surface, integrated in the car body, a specific electronic system and on board Energy Management System (EMS), linked to a storage element for PV energy. Most of the time, the main characteristic of the PV element is the peak power (Wp) under standard irradiance (1000 W/m², AM1.5 @25°C). This is a key parameter to predict the solar energy we can get and use from the sun each year. As the PV surface is not flat, but curved in a car solar roof, mismatches appear in term of irradiance and cells temperature. It results in energy losses due to non-uniformity in light incidence angle over the module surface. This is the topic of this report.

This work presents the conceptualization of an instrumented roof equipped with irradiance and temperature sensors. The aim of this report is to outline the manufacturing stages on a vehicle roof, from cell selection to module assembly, and finally to assembly of the outdoor monitoring system. As a curved roof induce losses due to PV exposition mismatches, we propose to measure, directly on real vehicle roof, irradiance and temperature homogeneity, thanks to a 5x5 individual sensor matrix coupled to a specific data logger configuration on a 1.4*0.9 m² vehicle roof. Two options were investigated: using photodiodes or existing solar cells as irradiance sensor. Due to representative surface of real cells and light collection in a module structure, individual solar cells are used. This study, over 8 days during August 2023, recorded target parameters in Le Bourget du Lac, France. For clear sunny days, Irradiance data reveals up to 250 W/m² (21%) difference between best and worst oriented cell on the roof. Regarding temperature, up to 13 °C difference is confirmed. For rainy days, we found less than 20 W/m² irradiance difference and less than 3 °C temperature homogeneity. These results are summarized in the figure below. Thus, we propose to consider irradiance and temperature mismatches only on clear sky conditions (direct irradiance as main energy contribution). These conclusions will be tested in our energy prediction model at vehicle level to estimate the accuracy/complexity of this approach.




| Delta values | Max(Gmax-Gmin) (W/m²) | Max(Tpvcellmax-Tpvcellmin) (°C) |
|---|---|---|
| 8/24/2023 | 255,67 | **12,22** |
| 8/25/2023 | 261,04 | **12,33** |
| 8/26/2023 | 210,00 | **13,00** |
| 8/27/2023 | 242,07 | **9,19** |
| 8/28/2023 | 240,16 | **9,59** |
| 8/29/2023 | 19,58 | **2,89** |
| 8/30/2023 | 367,27 | **13,89** |
| 8/31/2023 | 254,07 | **12,55** |

**Maximum values for irradiance homogeneity and cell temperature on solar roof over experiment time. It focuses only on maximum values**

This report illustrated the various stages in the implementation of a measurement bench, from design, installation, monitoring phase and data processing, recorded during 8 days, during August 2023, at INES site, Le Bourget du Lac, France.

A simple theoretical comparison confirmed that irradiance and temperature uniformity is mainly due to roof curvature. Energy calculations coupled with a full serial cells connection hypothesis and a curved surface (Radius of curvature =3 m) show that the energy harvesting is limited by 12 to 17% performance loss on clear sky sunny day, and 6% for rainy days. These values are valid for August, at Le Bourget du Lac, France, only.

This study should be done on one-year duration to collect representative data. Further steps will focus on energy model prediction at vehicle level (irradiance and temperature mismatch versus standard "x" % losses approach) to quantify the accuracy/complexity of both approaches. Another interesting work should be to install again this bench over a year to duplicate this study on several location.