Habilitation Thesis Abstract

Scientific Contributions to the Enhancement of Photovoltaic Panel Efficiency through Cooling

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The habilitation thesis synthesizes the scientific, professional, and academic contributions developed in the field of civil engineering and building services engineering, establishing a coherent research direction focused on improving the energy performance of photovoltaic (PV) panels through cooling solutions and their integration into buildings. The scientific approach is motivated by the need to enhance the efficiency of PV systems, in the context of the increasing use of renewable energy sources and the transition towards energy-efficient buildings. The research addresses both fundamental aspects related to solar energy conversion and the influence of temperature on the electrical parameters of PV panels, as well as the development, modelling, and validation of cooling solutions.

The first chapter of the thesis presents the author's scientific and professional achievements, highlighting the development of research and academic activities in the field of building services engineering, with a focus on the use of renewable energy sources and building energy efficiency. The author's activity is supported by scientific contributions published in specialized journals, participation in research projects, the development of simulation applications, and involvement in teaching activities and knowledge transfer to the economic sector. The research direction concerning PV cooling is grounded in numerical and experimental studies, the development of constructive solutions, and the analysis of their potential integration into buildings.

The second chapter presents the scientific contributions to improving the efficiency of photovoltaic panels through cooling. The factors influencing the electrical performance of PV panels are highlighted, with particular emphasis on solar irradiance and operating temperature. The research addresses two main directions: passive air cooling and active water cooling. For passive cooling, solutions based on the use of heat sinks mounted on the rear surface of photovoltaic panels were investigated. Particular attention was given to perforated heat sinks, which are intended to enhance air circulation and improve natural heat dissipation. The analyses considered temperature distribution, convective heat transfer, and the effect of the constructive configuration on the operating temperature of the panel.

An important aspect of the research is the analysis of the influence of wind direction and velocity on the cooling process of PV panels equipped with perforated heat sinks. Numerical modelling was used to evaluate operating conditions and heat dissipation performance in relation to environmental parameters. The results contributed to identifying suitable constructive configurations and establishing the foundations for passive cooling solutions applicable to real-world systems. Experimental investigations aimed to validate the numerical results and assess the behavior of PV panels under controlled conditions.

The experimental analysis was conducted using a testing infrastructure that enables the control of climatic conditions and solar irradiance levels. Different types of photovoltaic panels were investigated, with particular attention paid to the influence of temperature on their electrical parameters and efficiency. The results demonstrate the beneficial effect of heat sinks in reducing operating temperature and improving electrical performance. Comparative analyses aimed to identify the constructive configurations yielding the best results and to establish the foundations

for passive cooling solutions with potential applications in building-integrated photovoltaic systems.

Active water cooling constitutes the second major research direction. This approach involved investigating the use of a water-film heat exchanger installed on the rear surface of the PV panel to extract heat and reduce its operating temperature. Preliminary and in-depth numerical studies examined heat transfer between the panel and the cooling fluid, as well as the influence of operating parameters on system performance. Mathematical modelling and simulations performed in Matlab enabled the assessment of the thermal and electrical behavior of photovoltaic panels under different operating conditions.

Experimental contributions concerning water cooling focused on validating the numerical models and analyzing the potential for thermal energy recovery. The investigated solution enables not only a reduction in photovoltaic panel temperature and an improvement in electrical power output, but also the recovery and utilization of heat extracted by the cooling fluid. In this way, the research creates opportunities for integrating photovoltaic systems with domestic hot water production systems and other thermal applications within the framework of photovoltaic–thermal (PVT) systems.

Another area of contribution concerns the development of graphical user interfaces for simulating and evaluating the performance of PV panels. Applications were developed using Matlab and Visual Studio, together with an online simulator dedicated to PV and PVT systems. These tools enable the analysis of operating parameters, the estimation of energy production, and the assessment of the effect of cooling on panel efficiency. Through the development of these applications, the research findings are translated into accessible tools for students, researchers, and professionals in the field of building services engineering.

The thesis also addresses the integration of PV into buildings through numerical modelling and the analysis of energy performance under real operating conditions. Annual, monthly, and daily analyses were conducted, highlighting the influence of temperature and cooling solutions on electrical energy production. Research on building-integrated photovoltaic (BIPV) systems aims to correlate panel performance with building energy requirements and to identify efficient integration solutions within the building envelope, taking into account climatic conditions and the constructive characteristics of the panels.

The chapter dedicated to technology transfer and practical applicability highlights opportunities for valorizing the research findings through the development of constructive solutions and technical datasheets for heat sinks, as well as for the water-film heat exchanger. These contributions aim to facilitate the implementation of the investigated solutions in the design and construction of energy-efficient PV systems. The development of the web platform for performing calculations and results contributes to knowledge dissemination and the transfer of research findings to professional environment.

In conclusion, the habilitation thesis supports the development of innovative solutions for improving photovoltaic panel efficiency through cooling by combining numerical modelling, experimental validation, and practical applications. The results highlight the potential of passive and active cooling to reduce panel operating temperatures, improve electrical performance, and facilitate thermal energy recovery. Future research directions include the optimization of cooling solutions, the development of PVT systems, their integration into buildings, and the further development of simulation tools. Through its contributions, the thesis provides a relevant scientific and practical foundation for the development of efficient and sustainable photovoltaic systems.