# Habilitation Thesis Abstract

## Contributions to the Energy Efficiency of Double-Skin Façades and Photovoltaic-Thermal Systems for Buildings

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The habilitation thesis synthesizes the scientific, professional, and academic contributions developed after the award of the PhD degree, in the field of civil engineering and building services, establishing a coherent research direction on heat transfer and fluid flow in building envelopes and in solar energy systems. The scientific approach is motivated by the need to reduce the energy consumption of buildings, in the context of the increasing use of glazed envelopes and the integration of renewable energy sources into nearly zero-energy buildings. The research addresses both fundamental aspects of natural convection in asymmetrically heated vertical channels and the development, modelling, and experimental validation of applied solutions: ventilated double-skin façades, passive cooling of photovoltaic (PV) panels, and hybrid photovoltaic-thermal (PV/T) systems.

The first part of the thesis presents the author’s scientific and professional achievements, highlighting the context, motivation, and development of the research carried out within the Department of Building Services of the Faculty of Civil Engineering and Building Services in Iași, in collaboration with the Université de Reims Champagne-Ardenne (GRESPI laboratory), the National Institute for Research and Development URBAN-INCERC – Iași Branch, and Mohammed First University of Oujda. The thesis integrates the results published in ten scientific papers indexed in Web of Science (2012–2024), presented as a coherent sequence of research supported by national research projects. The common methodology combines experiments (flow visualisations, full-scale test stands, in-situ monitoring) with numerical modelling, their mutual validation being a constant of the entire activity.

Chapter I deals with natural convection in an asymmetrically heated vertical channel, the basic constructive element of double-skin façades. The experimental investigations, carried out in water, used laser flow visualisation techniques with discrete and continuous tracers, for three aspect ratios and for modified Rayleigh numbers between $4.3 \times 10^5$ and $4.5 \times 10^6$, corresponding to the boundary-layer flow regime. The results highlight the ascending flow along the heated wall and the reverse flow entering through the upper end of the channel, in the form of an eight-shaped recirculation structure with two cells, as well as the mechanism by which this structure develops from a single cell during the transient regime.

An important aspect of the research is the analysis of the influence of the aspect ratio and of the modified Rayleigh number on the flow structure, in steady-state and transient regimes. The experimental data were used to validate a two-dimensional numerical model of the flow in a double-skin façade, based on the finite volume method, which predicts the total recirculation length within about 6%. The model confirms the asymmetric character of the flow and the presence of the recirculation zone at the channel outlet, near the unheated wall, regardless of the configuration analysed. These results established the methodology of experimental validation of numerical models, subsequently applied to full-scale façades.

The second chapter presents the contributions concerning the thermo-aerodynamic behaviour and energy efficiency of ventilated double-skin façades. A three-dimensional numerical model of the façade channel in forced convection was developed and validated on an experimental stand, the deviations between calculated and measured temperatures being 0–6 °C. The numerical studies on the solar protection integrated in the channel examined the influence of the venetian blind slat angle and of the blind position on the dynamic insulation efficiency. The results indicate an optimum angle of 45°, for which the efficiency reaches 68.9%, and an optimum position close to the outer glazing, the efficiency ranging between 58% and 85% depending on the blind position and the inlet air velocity.

The in-situ experimental analysis was conducted on a full-scale double-skin façade located in Iași. Air and glazing surface temperatures, air velocities in the channel, and climatic parameters were monitored for

three ventilation modes in the hot season and for thermal buffer operation in the cold season. The results show that natural ventilation with combined lateral and vertical openings provides the best dynamic insulation efficiency (71.3%), higher than that of forced ventilation (50.9%), limiting the risk of channel overheating. In the cold season, the façade can provide partial or full heating of the adjacent room for solar radiation above 100 W/m$^2$, with a risk of condensation at high humidity.

Passive cooling of photovoltaic panels constitutes the third research direction, addressed in Chapter III. Copper heat sinks mounted on the rear surface of the panel were analysed, with perforated and non-perforated fins arranged horizontally and vertically, in six constructive variants. The CFD model developed simulates the entire air volume around a panel tilted at 45°, under real wind conditions; it was calibrated against the NOCT parameters (deviations of 0.28–1.98%), validated against experimental data from the literature, and verified by the grid convergence index method. The analyses considered temperature distribution, convective heat transfer coefficients, and the effect of the constructive configuration on the operating temperature of the panel.

The effects of solar radiation, ambient temperature, wind velocity, and wind direction on the operating temperature and energy production were evaluated. The optimum solution, the heat sink with horizontal fins perforated with Φ = 30 mm holes, leads to decreases in operating temperature of up to about 15 °C and to increases in power production ranging from 1.85% for front wind to 7.71% for side wind, and 6.49% for back wind. The cooling effect is most significant at low wind velocities and high solar radiation. The results also highlight the limits of passive air cooling and motivate the transition to active water-cooling solutions.

Chapter IV is dedicated to water-cooled hybrid photovoltaic-thermal systems. A dynamic numerical model was developed, based on the energy balance equations of the system layers and solved in MATLAB by the Runge–Kutta method, and used for the parametric analysis of the water velocity and water film thickness. The optimum parameters (0.035 m/s and 7 mm, at a water inlet temperature of 20 °C) reduce the cell temperature to 27.7 °C, the electrical power increasing from 258.8 W to 316.56 W, with a recovered thermal power of 1334.5 W; the electrical and thermal efficiencies are 19.07% and 80.3%, respectively. Under the real weather conditions of Iași, the cell temperature of the PV/T system was 33.8 °C, compared with 61 °C for the conventional panel.

The contributions concerning constructive water-cooling solutions were obtained through three-dimensional CFD simulations of a photovoltaic panel cooled by a serpentine and by a distributor/collector system, compared with the uncooled panel. Without cooling, at 1000 W/m$^2$, the panel temperature can exceed 110 °C, with a reduction in production capacity of up to 40%. The distributor/collector system provides a more uniform temperature distribution and is advantageous at low coolant velocities, whereas the serpentine is more efficient at high velocities, but with a thermal non-uniformity that may affect cell durability. The investigated solutions enable both an improvement in electrical production and the recovery of the heat extracted by the cooling fluid.

In conclusion, the habilitation thesis presents a coherent development of the research, from the fundamental study of natural convection in vertical channels, through double-skin façades, to photovoltaic and photovoltaic-thermal systems, combining numerical modelling with experimental validation. Chapter V summarises the general conclusions and the original contributions and proposes the career development plan. Future research directions include the integration of PV and PV/T panels into double-skin façades, the experimental validation and optimisation of passive cooling solutions, the development of the experimental programme on the PV/T prototype and the analysis of the impact of these solutions on nearly zero-energy buildings. In terms of teaching, the aim is to integrate the research results into the specialised courses and to supervise doctoral theses. Through its contributions, the thesis provides a relevant scientific and practical foundation for improving the energy efficiency of buildings.