Habilitation Thesis Abstract
CONTRIBUTIONS REGARDING ENERGY EFFIENCY AND COMFORT IN BUIDINGS INTEGRATING HVAC SYSTEMS BASED ON HEAT PUMPS , PHOTOVOLTAIC PANELS AND THERMAL STORAGE , IN THE CONTEXT OF TRANSITION TO A ZERO-EMISSION BUILDING STOCK

This habilitation thesis summarises the scientific, professional and academic activity carried out after the public defence of the doctoral thesis, in 1999, at the „Gheorghe Asachi" Technical University of Iași. The doctoral thesis, entitled *„Contributions to the theoretical and experimental study of low-temperature radiant electric heating systems"* and supervised by Prof. Dr. Eng. Theodor Mateescu, established the working method kept and developed in all subsequent work: the combined theoretical, numerical and experimental investigation of heat transfer processes in buildings and in their building services, with models validated on test rigs and prototypes built in the laboratory or in situ.

The post-doctoral research activity is structured along **four main directions**, presented in detail in Chapters 2.1 to 2.4 of this thesis. **Direction 1** (*renewable energy sources, heat pumps and thermal storage*) covers original solutions for geothermal heat exchangers with variable geometry, the uniform-heat-flux heat exchanger and the seasonal thermal accumulator, developed and experimentally validated within two research grants awarded through national competition, in which I was project director. **Direction 2** (*photovoltaic energy and PV panel cooling*) addresses the thermal management of PV modules, both passively, by means of air-cooled perforated-fin heat sinks, and actively, through photovoltaic-thermal (PVT) systems, quantifying the electrical power gain obtained by lowering the cell operating temperature. **Direction 3** (*ventilated façades*) treats the building envelope as an active component, through the integration of photovoltaic panels into the façade (BIPV) and the use of phase change materials (PCM) as a short-term thermal storage medium. **Direction 4** (*HVAC systems for buildings with special requirements*) brings together studies of indoor climate and indoor

environmental quality for heritage buildings, socio-cultural spaces and healthcare facilities, including the analysis of infectious aerosol dispersion in intensive care units.

The directions share a common starting point, the doctoral training in low-temperature radiant heat transfer, and the same working sequence: mathematical model, calculation tool, experimental verification. They differ in the building component they address: the energy source, the conversion of solar energy into electricity, the envelope and the indoor air treatment system.

The four directions converge towards a common objective: the nearly zero-energy building (nZEB), in which the renewable source, the envelope and the building services are designed as one system. The functional links between directions (the heat pump as the thermal source of the HVAC system, the photovoltaic panel turned into an envelope component, thermal storage in the ground mass or in the PCM layer) are themselves a research result and are summarised in Section I.2.

The original contributions consist of in-house calculation models and sizing algorithms, experimental prototypes built and tested, CFD and system models validated against measurements, and technical solutions transferable to industry. The results were disseminated through papers in Web of Science indexed journals and international conference proceedings, through communications at national scientific events and through workshops organised jointly with companies active in the field.

The teaching activity, carried out without interruption since 1991 in the Faculty of Civil Engineering and Building Services of the „Gheorghe Asachi" Technical University of Iași, has covered all academic ranks: junior teaching assistant, teaching assistant, lecturer and, since 2003, associate professor. It has been accompanied throughout by professional work in design, design verification, technical expertise and energy auditing, which kept the research topics directly connected to the real problems of building services practice.

Section 3.1 summarises the original contributions along the four research directions, and the conclusions of the technical chapters outline the prospects for further work.

Direction 1 — renewable sources, heat pumps and thermal storage. The uniform heat flux principle for the ground heat exchanger was validated numerically and experimentally and implemented in two prototypes built within the HEUTF and SHSRE grants. For a residential building in Iași with a heating load of 12 kW, the modular exchanger with variable geometry keeps the heat flux deviations below ± 8 %, compared with ± 35 % for a spiral pipe of constant diameter, and reduces the required land area by about 30 – 40 %. For the seasonal accumulator, insulating the enclosure with 60 mm of mineral wool increased the specific storage capacity in water from 11.09 kWh/m³ to 14.03 kWh/m³. Further work covers testing in soil, monitoring over complete annual cycles, a pilot installation coupling the exchanger with the accumulator, and direct measurement of the heat pump COP.

Direction 2 — photovoltaic energy and PV panel cooling. The operating temperature was confirmed as the decisive factor for module efficiency. The heat sink with perforated fins lowers the mean module temperature by 13 – 14 °C and raises the electrical output by 7.5 % without auxiliary energy, while active cooling (PVT) keeps the electrical efficiency at 95 – 98 % of the STC value and recovers heat at the same time. The prospects include topology optimisation of heat sinks, PVT systems with PCM, PVT – heat pump coupling, machine-learning control of the coolant flow and full-scale validation over an annual cycle.

Direction 3 — ventilated façades with BIPV and PCM. The optimum channel depth of the ventilated façade in the temperate-continental climate is 4 cm. Integrating the modules in the ventilated façade lowers their temperature by 12 – 15 °C compared with rooftop BIPV and raises the electrical efficiency by 5 – 8 %. A 10 cm PCM layer produces a time lag of 10 – 12 h and reduces the cooling demand by 22 – 28 %. Next steps are predictive façade control, micro-encapsulated PCM in a conductive matrix, semi-transparent BIPV in double-skin façades, full-scale validation of the BIPV + PCM façade and life-cycle cost analysis.

Direction 4 — HVAC systems for buildings with special requirements. CFD simulation combined with in situ monitoring was applied to a heritage performance hall, a cardiac intensive care unit and a 16th-century church. The results supported recommendations for limiting the dispersion of infectious aerosols (100 % fresh air, HEPA H13 filters, at least 12 air changes per hour), for keeping the relative humidity within 55 – 60 % in heritage spaces and

for choosing electric radiant heating in the church studied. The prospects include HVAC systems controlled on the basis of IoT sensors and artificial intelligence, coupling CFD with hygrothermal models of materials, LES/DES turbulence models and reduced-order models for a digital twin of the building.

In conclusion, the presented contributions offer—for each component—tools validated through measurements that can be utilized in the transition toward a zero-emission building stock; the four research directions converge on the same objective: the nearly Zero-Energy Building (nZEB), in which the renewable energy source, the building envelope, and the building services systems are designed as an integrated whole.

Future research aims to establish a recognized research line within the Department of Building Services Engineering at the Faculty of Civil Engineering and Building Services of the "Gheorghe Asachi" Technical University of Iași. This research will focus on integrated building-services systems—incorporating renewable sources, thermal storage, and predictive control—capable of simultaneously meeting the requirements for decarbonizing the building stock and ensuring high indoor environmental quality.

By combining fundamental research with experimental validation and practical applications, the thesis makes a solid and relevant contribution to the advancement of the field of building services engineering.