Improving Climate Control and Energy Performance in Greenhouses and Livestock Houses: Modeling Advances and Experimental Results

Socio-demographic trends, such as population growth and urbanization, are leading to a significant increase of the world food demand. At the same time, there is a shift of the human diet toward livestock products, vegetables, and fruit rather than cereals. In this context, greenhouses and livestock houses can play a primary role since they can supply the necessary agricultural products with higher yields than on-field crop production and extensive animal farming. One way in which productivity is enhanced in these agricultural buildings is by a fine-tuned control of the indoor climate conditions. For this purpose, mechanical climate control systems are often adopted, but they entail a considerable energy consumption whose estimated increase may jeopardize the transition toward a sustainable agriculture. The overall objective of this thesis, hence, is to contribute to the transition toward a sustainable agriculture by improving the energy performance for climate control of greenhouses and livestock houses.

To achieve this objective, a three-pronged approach was taken involving a literature review, experimental monitoring campaigns, and energy modelling activities. The literature review was performed to unpick the tangle of mutual relations between climate control and other domains of agricultural production. The nexus between energy performance and climate control was investigated analyzing real datasets acquired through monitoring campaigns performed in a greenhouse and two pig houses. This nexus was further studied adopting a numerical approach which led to the development and validation of three energy simulation models for greenhouses, broiler houses and pig houses. Each simulation model integrates the main features typical of greenhouses and livestock houses to accurately estimate the time profiles of lumped indoor climate conditions and thermal and electrical energy consumption. The opportunities in improving the energy performance and the indoor climate conditions provided by the developed energy models were explored by analyzing specific energy-related problems. The broiler house energy model, in fact, was adopted to evaluate the potentialities of a new primary energy approach for the energy-efficient envelope design of broiler houses. The same model was applied to evaluate the variation of energy consumption achieved by an improved ventilation strategy aimed at enhancing broiler welfare by reducing indoor noxious gas concentrations.

This thesis contributes to the transition toward a more sustainable agriculture providing new knowledge and tools necessary for improving the energy performance for climate control of greenhouses and livestock houses. The performed analyses, in fact, quantify potential decrease of energy consumption achievable through the implementation of energy-efficient measures at both envelope -thermal insulation- and climate control system -variable angular speed fans- level. Further energy-efficient measures could be evaluated adopting the developed energy simulation models that are valuable outputs of this investigation. These models, in fact, could have a positive impact at local level since stakeholders -farmers, engineers, and manufacturers- could adopt them as decision support tools for the evaluation of new technologies, strategies and solutions aimed at decreasing the overall energy consumption of greenhouses and livestock houses. These novel models represent also a robust starting point for future research in this field. Future advances may lead to the development of further calculation modules to evaluate other aspects of greenhouses and livestock houses, such as productivity variations, contaminant emissions and animal welfare. The new knowledge generated in this thesis could have positive impacts also at global level since it may represent the technical basis for new normative frameworks and incentive schemes aimed at improving the energy performance of climate-controlled agricultural buildings through a top-down approach.