

## **A CFD–crop modelling framework for the virtual assessment of dynamic lighting strategies in indoor cultivation systems**

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### **Abstract**

In indoor farming systems, the design of the cultivation environment and the selection of operating conditions are crucial for ensuring healthy crop development while reducing energy consumption. Plants are not passive components of the system: as growth progresses, their physiological activity and structural characteristics continuously evolve, modifying airflow resistance, heat exchange, and moisture release within the cultivation environment. Adapting environmental control strategies over time, rather than maintaining fixed set-points throughout the growth cycle, may significantly improve production efficiency and crop performance. However, experimental tests to analyse such strategies are often costly and time-consuming.

In this presentation, we propose a coupled model that virtually describes the crop–environment interaction over a full growth cycle, supporting the evaluation of cultivation-setting alternatives. The model is based on a computational fluid dynamics framework in which the crop is explicitly represented as an evolving component of the indoor farming system: at each growth stage, airflow is simulated by solving the unsteady incompressible Navier–Stokes equations, while crop-induced aerodynamic resistance is modeled through a porous-medium approach. The resulting velocity field is used to compute the spatial distributions of temperature, water vapor, and carbon dioxide concentration. Source and sink terms within the crop region are dynamically obtained from a transpiration model coupled with a crop growth model, developed by Van Henten in [1], formulated as a system

of ordinary differential equations. The model is validated using experimental measurements collected in a real vertical farming cell.

As a case study, the framework is employed to virtually assess dynamic lighting strategies in a single-layer indoor farming configuration with top air supply through a perforated panel. The analysis follows three steps: first, the model identifies the minimum airflow rate needed to keep relative humidity and canopy-level air speed within agronomically acceptable ranges; successively, thermal simulations under different LED intensity levels quantify the coupling between LED heat dissipation and air temperature inside the cultivation volume; finally, three equal-energy photoperiod treatments are simulated over the full cycle and compared against a dedicated experimental campaign reproducing the same recipes in the real growth cell.

The comparison between simulated and measured responses verifies the predictive capability of the virtual model and shows how a validated coupled CFD–crop model can reduce the experimental burden of testing dynamic lighting recipes, anticipate microclimatic responses before physical trials, and support energy-efficient, growth-stage-aware lighting management strategies for indoor farming systems.

**Keywords:** vertical farming; computational fluid dynamics; virtual model; dynamic lighting strategies; microclimate control

## References

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