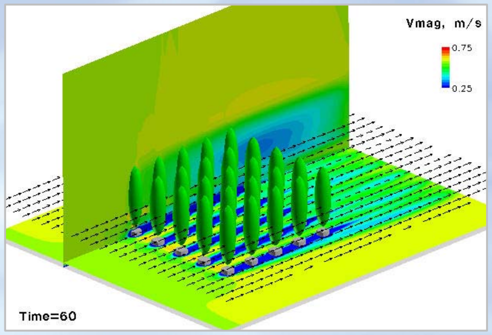
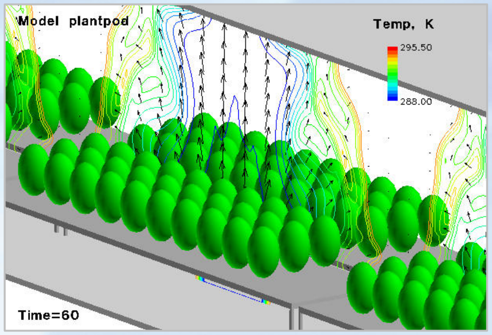
Using Computational Fluid Dynamics (CFD) for

Plant Transpiration Modeling

CFD is a powerful engineering tool for simulating all types of fluid flow. CFD simulations provide highly detailed descriptions of flow characteristics including values for velocities, pressures, temperatures, and other variables like water vapor content.

CFD significantly reduces design and development time, provides more detailed information than physical experiments, and quickly simulates a wide range of flow conditions.





Introduction

One key aspect to optimizing the distributed climate within indoor plant growth facilities, is understanding plant-air interactions. In particular, the leaf boundary layer climate and air flow through the plant crop itself.

Computational Fluid Dynamics (CFD) simulations provide details of the distributed climate, allowing for optimal overall plant facility design and performance. A unique proprietary method has been developed that can be applied to many types of produce crops (e.g., basil, arugula, tomato plants, etc). In addition, this simulation capability can be utilized for plant growth facilities of varying levels of complexity and size.

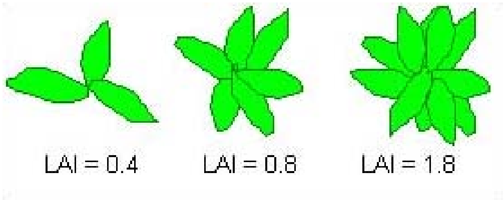
Climate heterogeneity and crop activity is increasingly becoming important for optimizing crop quality/yield. It is necessary to understand/quantify the spatial distribution of crop temperature and transpiration.

It has been demonstrated that a CFD modeling approach provides realistic simulations for a wide range of plant growth facilities, thus providing an invaluable tool for manufacturers and growers to improve facility control and design.

Plant Characteristic Modeling

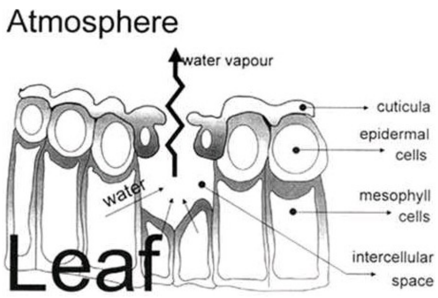
A porous media approach is used to model the dynamic effect of the plants on the flow. The insertion of plants into an air flow stream generates a fall in momentum. The sink of momentum due to the drag effect of the plants corresponds to the term **grad P of** the Navier Stokes Equations. This drag force can be expressed by means of a commonly used formula linking the drag effect of the leaf area index (LAI) and the air velocity by the means of a drag coefficient Cd:

grad P = LAI** x **Cd** x **density** x **u^2



Plant Transpiration Modeling

The algorithmic model for plant transpiration is accomplished by assimilating the plants into a porous medium exchanging latent and sensible heats with the environment.



The exchange of heat and water vapor between the plants and air is determined through the heat and mass balance of leaves with the air.

$$R_n - \frac{\rho C_p L_{ai}(T_1 - T_a)}{r_a} - L_{ai}\rho\lambda\frac{w_f - w_a}{r_a + r_s} = 0$$

where,

Rn	*net radiation*
Cp	*specific heat of air*
Lai	*leaf area index*
ra	*aerodynamic resistance of leaf*
rs	*stomatal resistance of leaf*
T1	*leaf temperature*
Ta	*air temperature*
wf	*humidity of leaf*
wa	*humidity of air*
ρ	*density of air*

The first term represents the net radiation, the second term represents the sensible heat exchange, and the third term the latent heat exchange (plant transpiration).

The "solar" energy absorbed by the crop plants is partioned into convective sensible heat and latent heat fluxes. This partition depends on the heat and water vapor exchanges (stomatal and aerodynamic) between the plants (modeled as porous media) and the air. The stomatal and aerodynamic resitances rely on the computed air speed and climatic conditions, and the resulting latent heat exchange (water vapor flux).

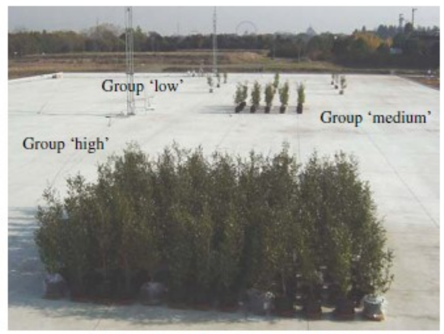
$$\lambda E = L_{ai}\rho\lambda\frac{w_f - w_a}{r_a + r_s}$$

"Experimental and numerical studies on the hererogeneity of crop transpiration in a plastic tunnel", T. Boulard, S. Wang. Computers and Electronics in Agriculture, 34 (2002).

Experimental / CFD Case Study

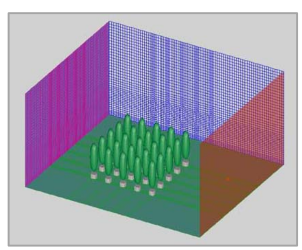
The publication "Field experiment on transpiration from isolated urban plants", Hagishima et al, 2007, presents the effects of pot plant density on transpiration rates in a series of field experiments.

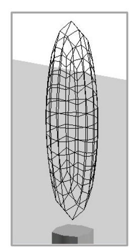
A CFD model has been developed representing one of the pot plant densities as described in the publication (medium density). The CFD simulation results are compared with the published experimental results.



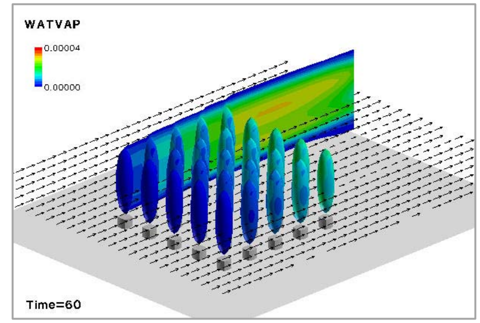
(a) Overview of the experimental site with the group 'high' plants in the foreground.

Some assumptions were made in order to best match the physical conditions of the experiment. For example, leaf area indices (LAI) are assumed to be moderate (LAI set to 2.0). In addition, the geometric envelope of each potted plant is estimated from the photos provided in the publication.





Case Study Results



The average transpiration rate for the center potted plant was computed to be 3.8e-6 Kg/m^2-s.

The publication reported that the highest transpiration rate measured was 456.25 g/day (see Table below).

Table II. Leaf areas and transpiration rates of three selected plants

Plant	Average transpiration rate of three runs (g day^{-1})	Transpiration rate rank among all test subjects	Number of leaves	Leaf area (m^2 pot^{-1})	Crown volume^a (m^3 pot^{-1})
#1	456·25	1st	2454	1·47	0·380
#2	227·25	23rd	1641	0·98	0·349
#3	149·5	50th	2015	0·99	0·264

The experiment determined the transpiration rate to be 3.6e-6 Kg/m^2-s.

The values are quite comparable, and confirm that the transpiration modeling approach is performing well.

For more Information

To learn more about the engineering services offered by Adaptive Research, or information regarding the **CAESIM** software, please email.

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